Long-Term Stewardship

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Science and Technology Roadmap (Draft)

IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY

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DRAFT FOR REVIEW

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DRAFT:
Long-Term Stewardship
Science and Technology Roadmap

Long-Term Stewardship Science and Technology Roadmap
Executive Committee and Workgroups

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Prepared for the
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Idaho Operations Office

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EXECUTIVE SUMMARY

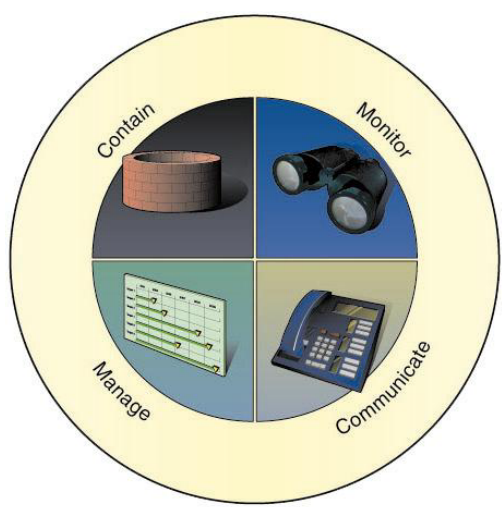
The Department of Energy (DOE) defines long-term stewardship (LTS) as "the physical controls, institutions, information, and other mechanisms needed to ensure protection of people and the environment at sites where DOE has completed or plans to complete 'cleanup' (e.g., landfill closures, remedial actions, removal actions, and facility stabilization). This concept of long-term stewardship includes, [among other things], land-use controls, monitoring, maintenance, and information management" (DOE 2001a, Vol. I, p. 1). According to its latest published estimate, DOE will be responsible for LTS at approximately 129 sites. The residual hazards at some of those sites—notably those from radioactive materials and toxic metals—will remain as potential threats to health and the environment for tens to thousands of years. This means that LTS must continue long after the current plans for site cleanup or closure are completed.

Science and Technology (S&T) has a critical LTS role in that DOE needs knowledge (science) and tools (technology) beyond what it already has to ensure that planning and implementation will result in efficient and effective LTS over tens to thousands of years. In general, this means moving the LTS state-of-the-art in S&T into the state-of-the-practice at DOE sites. Site stewards also need better information and resources to work more effectively with regulators, stakeholders, and others that influence decisions in exploring whether a new approach may work better than an accepted, or even prescribed, technology.

The LTS S&T Roadmap has been developed to aid DOE in identifying and cost effectively implementing knowledge and tools at DOE LTS sites. The Roadmap recommends research and development (R&D) pathways to provide a system of integrated capabilities needed for DOE to influence LTS policy and best manage investments to implement an effective LTS program. The areas of R&D covered in this document offer possibilities to realize significant performance improvements and cost savings in the near term (within the next 2 to 10 years). For purposes of developing the Roadmap, this effort targeted the FY 2003–FY 2008 planning cycles, with some recommended pathways extending to FY-2012.

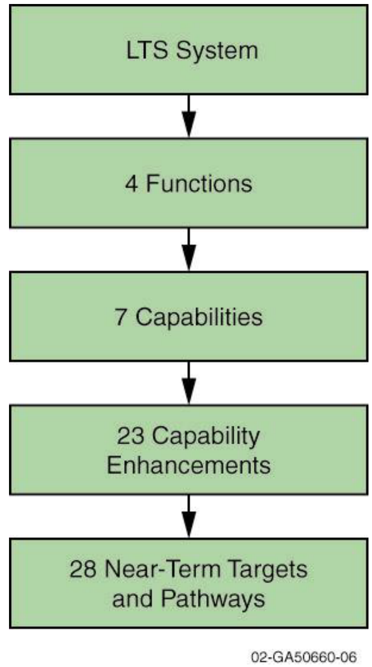
The Roadmap was compiled by an interdisciplinary team of subject matter experts from industry and academia, federal and state regulators, stakeholder groups, DOE national laboratories, DOE site contractors (end users), and other federal agencies. This Roadmap team was directed to concentrate its efforts on meeting immediate LTS needs by (1) identifying gaps in existing LTS capabilities; (2) seeking near-term opportunities to perform essential LTS functions at lower risk to human health and the environment, at lower cost (especially at lower life-cycle cost), or with less technical uncertainty; and (3) applying the results of research or transferring promising technology possibilities into implementable systems for LTS sites.

LTS as a System



Long-term stewardship of a site with residual contamination must be viewed as a system made up of many interrelated and interacting components and activities. The essential functions this system must perform are to ***contain*** the residual contaminants, ***monitor*** the site and the entire LTS system, ***communicate*** within and beyond the LTS system, and ***manage*** the system. By applying this system perspective, the Roadmap team identified seven capabilities essential to fulfilling these four functions:

- Key Capability 1. Site Conceptualization and Modeling Tools
- Key Capability 2. Contamination Containment and Control Systems
- Key Capability 3. Sensors and Sensor Systems for Site Monitoring
- Key Capability 4. Preservation and Communication of Site Information
- Key Capability 5. Site–Community Relations
- Key Capability 6. LTS System Performance Verification and Monitoring
- Key Capability 7. Effective and Survivable Land-Use Controls.



Under each key capability, the team listed one or more enhancements with associated near-term R&D targets that, if achieved, would address deficiencies in existing LTS capabilities or substantially improve a capability to reduce risk, cost, or uncertainty (see Table ES-1). The 23 capability enhancements and 28 associated R&D targets identified in the Roadmap will focus LTS S&T efforts and provide an LTS system that is resilient to human and natural forces, effective in protecting human and environmental health, and efficient in its use of national and local resources.

The LTS system to be developed by implementation of this Roadmap will provide a strong foundation for continued improvement of LTS capabilities. The integrated Roadmap schedule provides a pathway to develop the components of the overall system. Figure ES-1 shows the recommended annual investment and the cumulative completion of capability enhancement targets under the investment scenario. It should be recognized that for many of the targets, significant practical value will be realized prior to completion of the target.

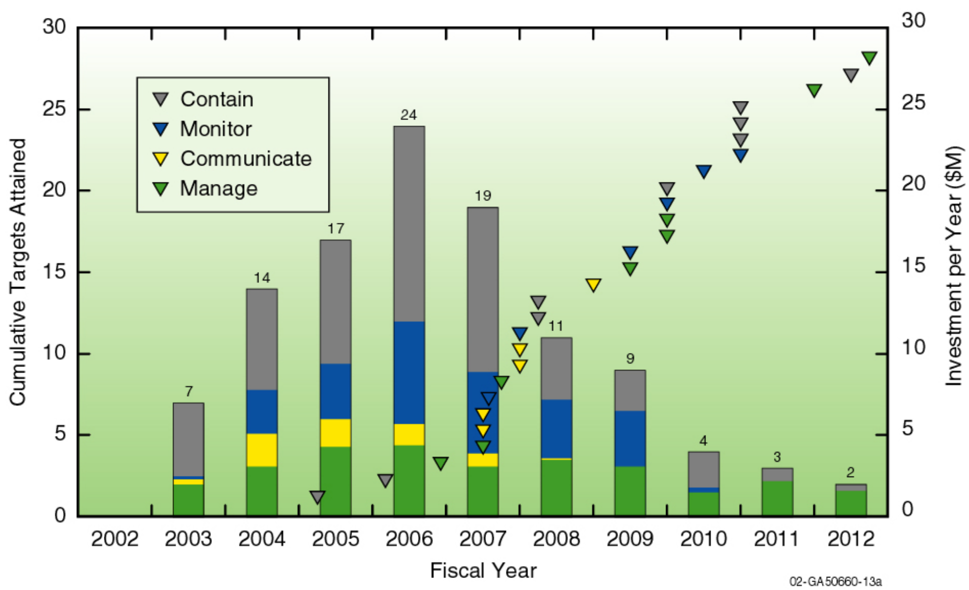


Figure ES-1. Projected Investments and Cumulative Targets Attained through FY 2012 (total cost: $110M in FY03 dollars)

Table ES-1. Capability Enhancements Necessary for a Long-Term Stewardship System

CONTAIN Residual Contaminants

Key Capability 1. Site Conceptualization and Modeling Tools

Enhancement 1.1	Improve geologic-hydrologic-biological-chemical-thermal conceptual modeling for long-term forecasting
Enhancement 1.2	Provide tools for long-term forecasting of environmental conditions relevant to predicted end states
Enhancement 1.3	Provide tools for modeling the community at risk
Enhancement 1.4	Conceptualize and predict containment/control system performance, including potential failure modes and levels of failure

Key Capability 2. Contamination Containment and Control Systems

Enhancement 2.1	Engineer the geologic-hydrologic-biological-chemical-thermal environment to limit contaminant toxicity and mobility
Enhancement 2.2	Design, build, and operate alternative (next-generation) containment and control systems

MONITOR the Site and the LTS System

Key Capability 3. Sensors and Sensor Systems for Site Monitoring

Enhancement 3.1	Identify contaminant monitoring needs for all media of potential transport or exposure and fill sensor technology gaps where monitoring solutions are needed
Enhancement 3.2	Establish site-specific parameters for environmental exposure routes and for both occupational (on-site) and non-occupational (community at risk) human routes of exposure
Enhancement 3.3	Improve sensors and sensor systems for monitoring active and passive safety systems

COMMUNICATE Within and Beyond the LTS System

Key Capability 4. Preservation and Communication of Site Information

Enhancement 4.1	Provide components for an integrated information visualization and display system
Enhancement 4.2	Provide an information system module for communicating system performance data
Enhancement 4.3	Provide options for intergenerational information archiving

Key Capability 5. Site–Community Relations

Enhancement 5.1	Improve understanding of what affects public trust and confidence
Enhancement 5.2	Involve the community in the conduct of site stewardship
Enhancement 5.3	Identify and solve problems that can undermine reliability and constancy in LTS institutions

MANAGE the LTS System

Key Capability 6. LTS System Performance Verification and Monitoring

Enhancement 6.1	Provide techniques and technologies to demonstrate, verify, and monitor long-term performance and management of contamination containment and control systems.
Enhancement 6.2	Improve tools to verify performance of contamination containment and control and monitoring subsystems
Enhancement 6.3	Provide tools to verify and monitor the overall (technical and non-technical) performance of the LTS system
Enhancement 6.4	Integrate preventive maintenance requirements into site subsystems
Enhancement 6.5	Improve tools for collecting, analyzing, evaluating, and disseminating performance data
Enhancement 6.6	Develop science to ensure continuous improvement in stewardship implementation

Key Capability 7. Effective and Survivable Land-Use Controls

Enhancement 7.1	Develop legal pathway modules to help identify potential legal strategies, assess established agreements, and develop draft alternative legal instruments
Enhancement 7.2	Provide intergenerational archive options for maintaining land-use control information.

Benefits and Critical Messages

This Roadmap recommends R&D pathways that will provide a system of integrated LTS capabilities needed for DOE to influence LTS policy and best manage investments. Implementing this LTS S&T Roadmap will provide several near-term programmatic benefits for DOE:

1. The Roadmap presents a vision for a full suite of LTS capabilities and identifies near-term enhancement opportunities that provide for step-change improvements in risk reduction, cost reduction, and assuring timely schedule completion.

2. The Roadmap identifies a broad spectrum of tools needed to fill an LTS Technology Toolbox that will link state-of-the-art technologies with the state-of-the-practice for LTS planning and operations to enhance DOE's ability to cost effectively meet closure schedules and keep LTS commitments to local communities and other stakeholders.

3. The Roadmap is a catalyst for coordinating and integrating dispersed efforts within DOE and with other federal agencies in developing technology to improve cleanup and stewardship.

The LTS S&T Roadmap team learned a great deal from the roadmapping effort. Two specific messages need to be stated explicitly:

- **Message 1: A Strategic Plan for LTS Science and Technology Will Help DOE with Site Closure Decisions.** DOE has invested a good deal in S&T to address technical issues raised in the course of environmental management of its sites. However, DOE has not yet developed a strategic vision and plan encompassing all of the S&T required to assure regulators, stakeholders, and potential stewards that LTS will be effective for the considerable periods of time during which residual contamination will present risks. DOE will use this Roadmap to establish the strategic vision for LTS S&T and develop an LTS S&T Strategic Plan.

- **Message 2: To Be Effective in the Long Term, Stewardship Must Be Approached as a System.** The integrated schedule presented in the Roadmap provides a pathway to develop the components of the overall system in a manner that allows early implementation of portions of the system while other portions are still under development. As such, capability enhancements can, and should, be implemented as sites gain experience with their particular stewardship requirements. Each capability within the LTS system adds intrinsic value toward meeting LTS objectives, but the greatest benefit will be realized only when those capabilities and associated tools are employed as an integrated system.

The benefits provided by this LTS S&T Roadmap can be expanded and improved with the participation of other state and federal agencies and non-governmental organizations with recognized expertise and the willingness to participate. A cooperative and coordinated effort between DOE and other agencies is needed, and this Roadmap can play an important role in that effort. DOE can learn from others, just as others can benefit from DOE efforts and lessons learned. Additionally, because the time frame of the Roadmap was restricted to the near term, some important capability enhancements were not identified nor were related enhancement pathways developed. To provide a more comprehensive, long-term view, the Roadmap should be expanded to provide needed longer-term benefits. The result of these broader efforts would be a follow-on S&T Roadmap providing for LTS capabilities and technologies applicable to a wider range of sites and situations than those covered herein.

CONTENTS

FIGURES AND TABLES

ACRONYMS

BWXT	Babcock & Wilcox Technologies
CAR	community at risk
CC&C	Contamination Containment and Control (workgroup)
CERCLA	Comprehensive Environmental, Response, Compensation, and Liability Act
DMIP	Decision Making and Institutional Performance (workgroup)
DOD	Department of Defense
DOE	Department of Energy
DQO	Data Quality Objective
EMSP	Environmental Management Science Program
EPA	Environmental Protection Agency
ET	evapotranspiration
GHBCT	geologic-hydrologic-biologic-chemical-thermal
GIS	geographic information system
ICT	information and communication technology
IM	information management
INEEL	Idaho National Engineering and Environmental Laboratory
IV&D	information visualization and display
LTS	Long-Term Stewardship
M&S	Monitoring and Sensors (workgroup)
MSW	municipal solid waste
NRC	National Research Council
OSHA	Occupational Safety and Health Administration
OST	Office of Science and Technology
R&D	research and development
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
RFSWG	Rocky Flats Stewardship Working Group
S&T	science and technology
SSAB	Site-Specific Advisory Board
SSIC	Safety Systems and Institutional Controls (workgroup)
SVE	Soil Vapor Extraction
SVOC	semi-volatile organic compound
VOC	volatile organic compound

GLOSSARY

Active Safety System	A Site Safety System *(see def.)* that requires a “human in the loop” (someone taking action) to protect persons in the event of an exposure incident, such as a warning communications system.
Enhancement	An improvement to a Key Capability *(see def.)* recommended by the Roadmap ream to achieve an efficient and effective LTS system. An Enhancement addresses an area of the capability needing improvement and the recommended direction of improvement by specifying the addition, extension, or integration of specific tools and methods.
Key Capability	A capability is a set of basic skills, tools, and methods necessary to perform one or more work functions. A Key Capability is a group of related capabilities used in the roadmap for organizational purposes. For example, to perform the Monitor function, one must have sensors and sensor systems for site monitoring (Key Capability #3).
Passive Safety System	A Site Safety System *(see def.)* designed to perform its protective function without requiring intervention by a person, such as a fence or physical barrier.
Site Safety System	A combination of technology (hardware and software), practices, and institutional controls used by a site to protect people from the hazards represented by residual contamination. Examples included fences, monitoring devices, sampling routines, and deed restrictions.
Target	A specific, measured step for an identified Enhancement *(see def.)*, often specifying both a level of improvement and a timeframe to complete the improvement. Targets are the most specific recommendations contained in the Roadmap, indicating not just what to improve, but also by when and by how much.

1. INTRODUCTION

1.1 The Department of Energy's Long-Term Stewardship Challenges

In October 2001, the U.S. Department of Energy (DOE) published its *Long-Term Stewardship Study* (LTS Study) in final form (DOE 2001a). The definition of 'long-term stewardship' (LTS) used in the LTS Study originated in DOE's 1998 Settlement Agreement related to the Programmatic Environmental Impact Statement for the DOE weapons complex sites.

> [LTS is] the physical controls, institutions, information and other mechanisms needed to ensure protection of people and the environment at sites where DOE has completed or plans to complete "cleanup" (e.g., landfill closures, remedial actions, removal actions, and facility stabilization). This concept of long-term stewardship includes, [among other things], land-use controls, monitoring, maintenance, and information management.
>
> (DOE 2001a, Vol. I, p. 1)

The Preface to the LTS Study states that it "is not a policy document and does not indicate the specific LTS actions that the Department [DOE] will take." Rather, the study's stated purpose is to "identify programmatic and cross-cutting issues and information that DOE should consider while implementing its LTS activities" (DOE 2001a, Vol. I, pp. i, 3). The Preface further notes that the LTS Study and the public comments to its earlier draft version (included, with DOE responses, in Volume II of the LTS Study) address eight key challenges DOE faces in dealing with LTS:

- Incorporating LTS considerations into site-specific cleanup decisions to improve DOE's ability to plan for and implement LTS.
- Ensuring the continued effectiveness of LTS for long periods of time and if property ownership changes to other federal or non-federal entities.
- Developing processes for meaningful public involvement in LTS decisions and plans.
- Building partnerships with state, local, and Tribal governments to plan for LTS activities, land use, enforcement of hazard controls [1] and information management requirements.
- Ensuring long-term public access to information and outreach efforts about residual risks to continue protection of human health and the environment.
- Providing reliable and sufficient funding for needed LTS activities into the future.
- Developing mechanisms for the sustainability of LTS, focusing on vigilance of duty, adaptability for societal changes, and commitment to advances in science and technology (S&T).
- Considering ways to minimize the need for eventual LTS in the planning and operation of new missions and facilities.

According to its latest published estimate, DOE will be responsible for LTS at approximately 129 sites (DOE 2001b, pg. 2-4). Some of the residual hazards at those sites—notably those from radioactive materials and toxic metals—will remain as potential threats to health and the environment for tens to

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[1] In the Long-Term Stewardship S&T Roadmap, the systems implemented to enforce hazard controls at a LTS site are generally referred to as "safety systems." See Section 2.3.1 for a more detailed characterization of site safety systems, including the distinction between active and passive safety systems.

thousands of years.[2] This means that LTS must continue long after the current plans for site cleanup or closure are completed. Figure 1-1 identifies the expected number of sub-portions of DOE sites performing LTS activities over the next 100 years. (Some larger DOE sites – such as Savannah River, Hanford, or the Idaho National Engineering and Environmental Laboratory (INEEL) – consist of many sub-portions).

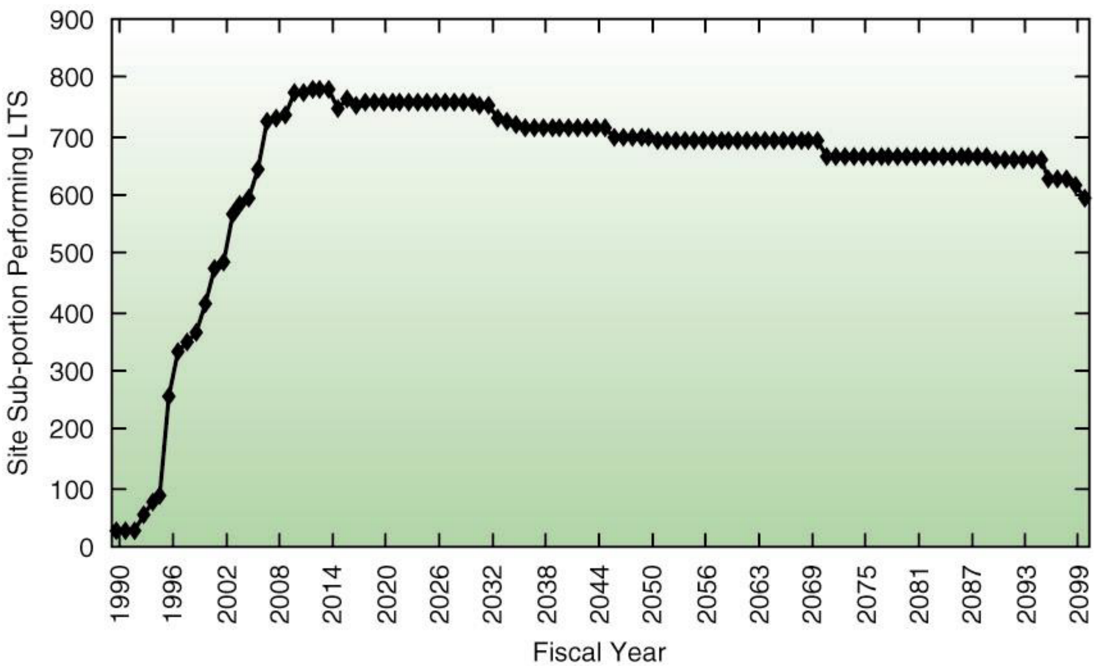

Figure 1-1. Number of Sub-Portions of DOE Sites Performing LTS Activities

1.2 The Role for Science and Technology in Long-Term Stewardship

Science and technology can help in meeting the LTS challenge in two major ways:

- Plan for the long term now. As the first of DOE's LTS challenges recognizes, requirements for stewardship must be weighed as part of remediation decisions and actions in planning, selecting, and implementing the proposed cleanup (see Figure 1-2). In a recent report to DOE, a National Research Council (NRC) study committee recommended that, to address the risks and uncertainties of LTS, a systematic approach to cleanup be developed in which contaminant reduction, contaminant isolation, and stewardship are considered in an integrated and complementary fashion (NRC 2000). Planning for LTS needs to start when planning for cleanup starts. In particular, the cost and performance of LTS measures over time needs to be known and balanced against the cost of using various amounts of contamination reduction and contamination isolation measures.

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[2] A comprehensive and technically detailed inventory of the known residual hazards at all DOE sites scheduled for eventual closure (return of property to non-DOE uses) can be found in DOE 2001b, Volume II.

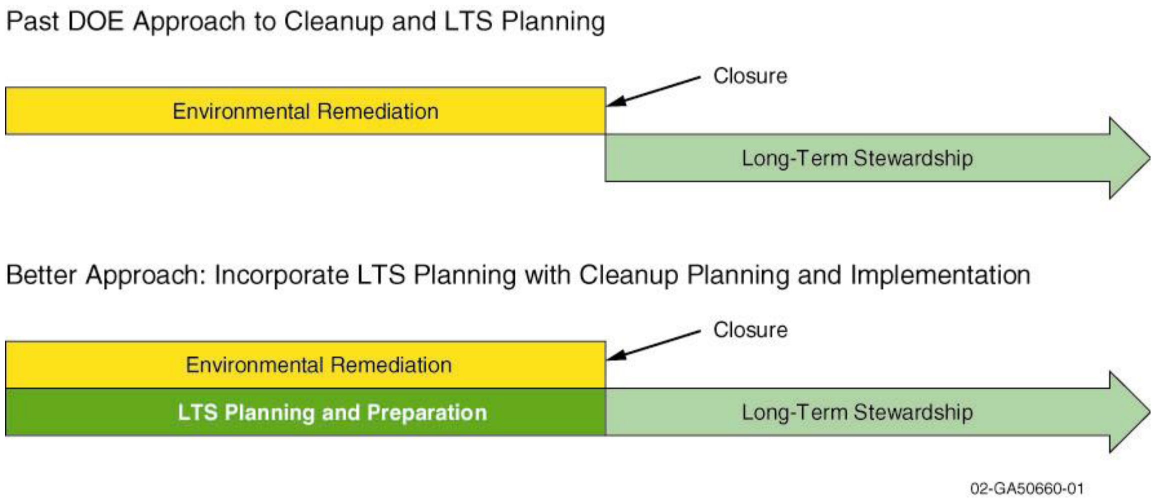


Figure 1-2. Past DOE versus Better Approach to Cleanup and LTS Planning.

- Improve LTS Operations. Scientific research and technology development can provide improved tools and techniques to perform LTS better and at less cost. In general, this means moving the state-of-the-art in S&T into the state-of-the-practice at DOE sites. For example, site-specific cost and performance parameters (derived through feasibility studies) are needed to move technologies that have been successfully demonstrated at the "proof-of-principle" stage off the shelf and into practice. Site stewards also need better information and resources to work more effectively with regulators, stakeholders, and other decision influencers in exploring whether a new approach may work better than an accepted, or even prescribed, technology (see Figure 1-3).

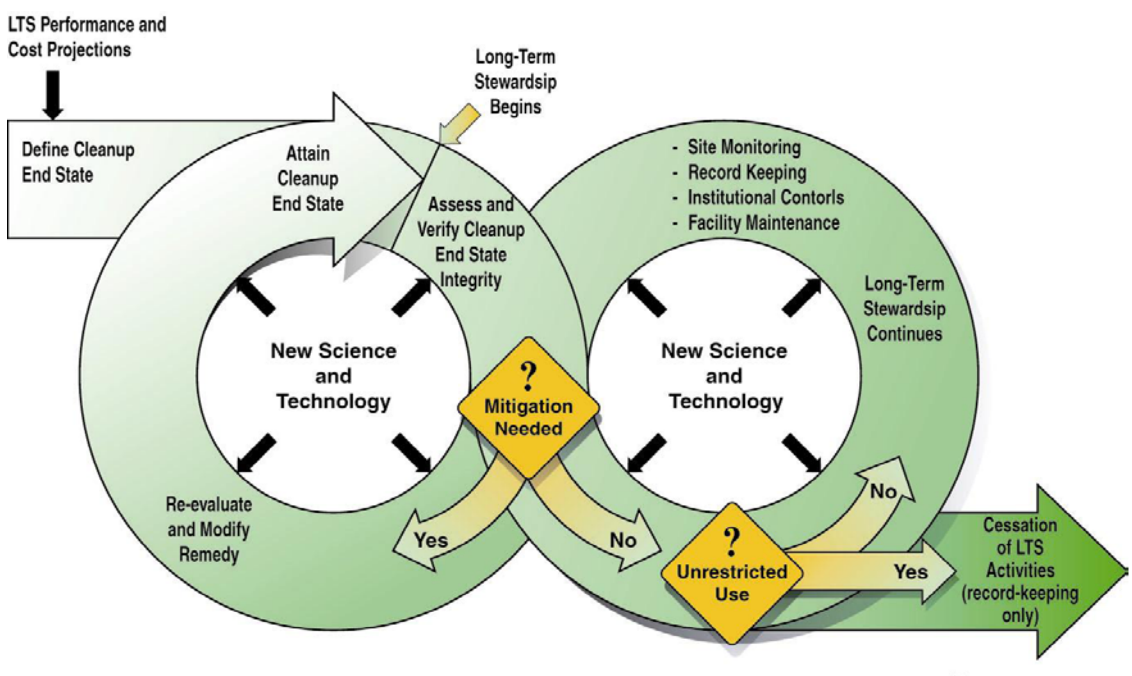


Figure 1-3. Changing Knowledge and Technology Will Continue to Affect LTS.
(Source: DOE 2001a, Exhibit 10-3, Vol. I, p. 127.)

To use S&T to plan for the long term and improve LTS operation, DOE will need knowledge (science) and tools (technology) beyond what it already has. Many S&T questions exist for which there are no simple answers. Examples include the long-term performance of caps in response to environmental factors, or the long-term performance of and maintenance requirements for monitoring systems. Answers to these questions have significant impact on the life-cycle costs and reliability of the stewardship system at many LTS sites.

1.3 The LTS S&T Roadmap

This Roadmap recommends research and development (R&D) pathways to provide a system of integrated capabilities needed for DOE to influence LTS policy and best manage investments to implement an effective LTS program. The Roadmap was compiled by an interdisciplinary team of subject matter experts from industry and academia, federal and state regulators, stakeholder groups, DOE national laboratories, DOE site contractors (end users), and other federal agencies (see Appendix A).

The LTS S&T Roadmap team was directed to concentrate its efforts on meeting immediate needs by (1) identifying gaps in existing LTS capabilities; (2) seeking near-term opportunities to perform essential LTS functions at lower risk to human health and the environment, at lower cost (especially at lower life-cycle cost), or with less technical uncertainty; and (3) applying the results of research or transferring promising technology possibilities into implementable systems for LTS sites.

The areas of R&D covered in this report offer possibilities to realize significant performance improvements and cost savings in the near term (within the next 2 to 10 years). For purposes of developing the Roadmap, this effort targeted the FY 2003–FY 2008 planning cycles, with some recommended pathways extending to FY 2012.

The process employed by the Roadmap team appears in Appendix B; the remainder of this chapter introduces the principles by which the Roadmap was developed and the major themes reflected in Chapters 2 through 4.

1.3.1 How to Succeed at Long-Term Stewardship

Common sense, as well as science, tells us there are some fundamental guiding principles that must be followed if any long-term activity (one that continues for tens to thousands of years) is to succeed. These are:

- **Don't fight Mother Nature.** Scientists and engineers are well aware that human activities cannot violate "laws of physics" such as the laws of thermodynamics. In many instances, however, we have tried to "get rid of" or control the hazardous byproducts of human activities in ways that are at odds with the natural processes controlling environmental systems (ecological as well as physical systems) over long periods of time. We need to learn how to work with these natural processes, so they are not working against us.
- **Don't fight human nature.** For many reasons—such as national security, political expediency, or avoiding an onerous consequence (such as justifying our actions to others)—we have often avoided dealing with the complexities of human behavior in social settings in order to get something done quickly. This is particularly true of the complex behaviors in a representative democracy that prizes individual expression, cultural diversity, and accountability of political institutions that are supposed to be by, for, and of the people. If LTS activities must endure for tens to thousands of years, they have to work with social realities. Thus, the science needed for

LTS includes social science, as well as the physical and environmental sciences needed to work with natural processes and systems.

- **Don't fall asleep at the wheel.** Stewardship activities require a constant vigilance over time. We know how to do many of these things well for relatively short periods—months to years, but we often fail at keeping them up for even a decade or two, much less for centuries. Some of the problems can be helped with physical science and "hard" technologies; others need a better understanding of social environments than we now have. The toughest problems will require an integration of techniques informed by both the physical and social sciences.

- **Don't drop the baton.** LTS is a necessity because we have no other choice but to manage the risks to human health and the environment posed by residual hazards we cannot now remove. The risks will not go away with the loss of historical data or because our attentions are diverted by other interests or opportunities. It is critically important that the essential details of site characterization and remediation are preserved over time. If not, the details needed to protect the public and the environment and to ensure informed future site use decisions will be lost.

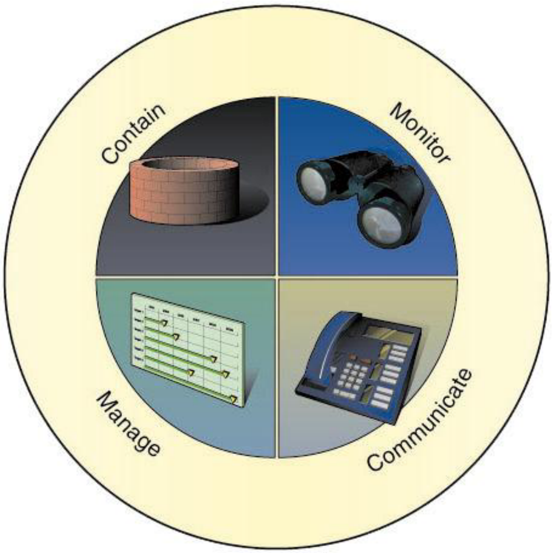
- **Don't put all your eggs in one basket.** LTS systems should be designed for defense-in-depth, which eliminates "single-point failures" from the system. The goal for the stewardship system is to define and monitor indicators of component failure (for example, failure of a sensor or a physical access control) so that the site steward(s) can intervene effectively to prevent any system failure that could result in a contaminant release in excess of the regulatory standard. In this document, the Roadmap team uses the term "failure" to indicate the occurrence of a component failure, not a system failure.

Throughout this report, these guiding principles are invoked, albeit in more technical terms, to explain why DOE needs some particular key capability or capability enhancement for LTS.

1.3.2 Long-Term Stewardship as a System

The same approach that engineers apply to things like moon rockets, the international telephone system, or the Internet can be applied to the totality of stewardship activities at a site, namely, each is viewed as a complex, integrated system. Looking at site stewardship, the LTS S&T Roadmap team agreed that an integrated LTS system must perform four functions:

- **Contain** the residual contamination
- **Monitor** the site and the LTS system for the site
- **Communicate** both within and beyond the LTS system
- **Manage** the system (implement and verify performance against design for all site containment, monitoring, and communication activities; continue to operate, maintain, and verify performance of all system components; periodically re-evaluate activities for potential performance improvements with respect to cost and risk reduction).



These four essential functions are easily remembered via the equation:

$$\mathbf{S = (MC)^2}$$

where ‘S’ refers to stewardship as a system, and ‘$(MC)^2$’ refers to each of the four functions identified.

As with any complex system, having most or even all of the individual functions needed for stewardship does not mean the system will work as intended, if at all. Those functions must be integrated as a cohesive, synergistic whole to responsibly and effectively achieve LTS objectives.

The well-established, basic principles of system engineering apply to site stewardship as a system:

1. Individual LTS subsystems may involve one or more of the four functions. Some of these, such as contamination containment units or information networks, may be rightfully described as “systems” themselves. With respect to the larger LTS system, however, they are all subsystems or components.

2. Optimization of subsystems or components individually typically results in sub-optimization of the system.

3. System performance metrics should drive subsystem/component requirements.

By applying this system perspective, the Roadmap team identified seven capabilities essential to fulfilling the four functions of an LTS system:

- Key Capability 1. Site Conceptualization and Modeling Tools
- Key Capability 2. Contamination Containment and Control Systems
- Key Capability 3. Sensors and Sensor Systems for Site Monitoring
- Key Capability 4. Preservation and Communication of Site Information
- Key Capability 5. Site–Community Relations
- Key Capability 6. LTS System Performance Verification and Monitoring
- Key Capability 7. Effective and Survivable Land-Use Controls.

Under each key capability, the team listed one or more enhancements with associated near-term R&D targets, which, if achieved, would address LTS deficiencies in existing capabilities or substantially improve a capability with respect to reducing risk, cost, or uncertainty. Key capabilities and associated enhancements are discussed in detail in Chapter 2.

The research, development, and demonstration tasks required to achieve each of the R&D targets were laid out in pathways, which together constitute the LTS S&T Roadmap. Chapter 3 summarizes R&D pathways to achieve these targets within the next five to ten years, and outlines the impact and benefits of the recommended enhancements for the DOE stewardship program. Appendix C provides the details of the tasks in each pathway.

2. KEY CAPABILITIES REQUIRED AND ENHANCEMENTS RECOMMENDED FOR AN LTS SYSTEM

2.1 Introduction

As explained in Chapter 1, the equation S = $(MC)^2$ is meant as an easily remembered shorthand for an overarching principle that emerged from the efforts of the Roadmap team to identify the essential, highest priority capabilities needed for a DOE site entering LTS:

> Long-term ***stewardship*** of a site with residual contamination must be viewed as a system. This LTS system includes the site but extends beyond it. The essential functions this system must perform are to ***contain*** the residual contaminants, ***monitor*** the site and the entire LTS system, ***communicate*** within and beyond the LTS system, and ***manage*** the system.

2.1.1 Key Capabilities of an LTS System

As discussed in Chapter 1, the Roadmap team identified seven key capabilities essential for a long-term functioning stewardship system; these seven key capabilities are the objectives supported by the S&T Roadmap. In this chapter, each Key Capability is discussed under the LTS core function (i.e., Contain, Monitor, Communicate, or Manage) to which it is most relevant (see Figure 2-1). However, all the key capabilities have some connection with at least two of the core functions, and some capabilities are important to all four functions. For example, although Key Capability 6, *LTS System Performance Verification and Monitoring*, is discussed under the Management function, it is obviously important to all four core functions. Figure 2-2 illustrates the interdependence among the Key Capabilities.

2.1.2 Recommended Enhancements to Key Capabilities

Working from the seven capabilities, the Roadmap team identified potential S&T-based enhancements that form the basis for the LTS S&T Roadmap. Initially, the team reviewed the previously developed Technology Profile (INEEL, 2001a) and Technical Baseline (INEEL, 2001b) documents. From this review, it became readily apparent that DOE would be better served by a roadmap that focused on a limited number of enhancements to key capabilities rather than on hundreds of specific technologies. Eighty-eight capability enhancements, each with a substantive S&T component, were initially identified. These enhancements were then prioritized according to their ability to provide one or both of the following benefits:

1. Without the enhancement, DOE closure sites may have difficulty meeting regulatory or statutory requirements.
2. The enhancement would substantially reduce risks to human health or the environment, reduce life cycle stewardship costs, or decrease technical uncertainties.

In the first case, the enhancement fills an unmet need of site stewardship. In the second, the enhancement substantially increases effectiveness and efficiency in the long term.

Based on this prioritization, the initial list was refined to the 23 enhancements most important to the LTS program. Additionally, the Roadmap team defined specific targets that could be achieved in the near term (within the next two to ten years) for these capability enhancements. Table 2-1 shows the key capability and enhancements structure used by the LTS S&T Roadmap. Key capabilities are identified by a whole number from 1 to 7 (for example, Key Capability 5). Enhancements and their respective targets are identified by a decimal number (as in Enhancements 5.1 through 5.3.).

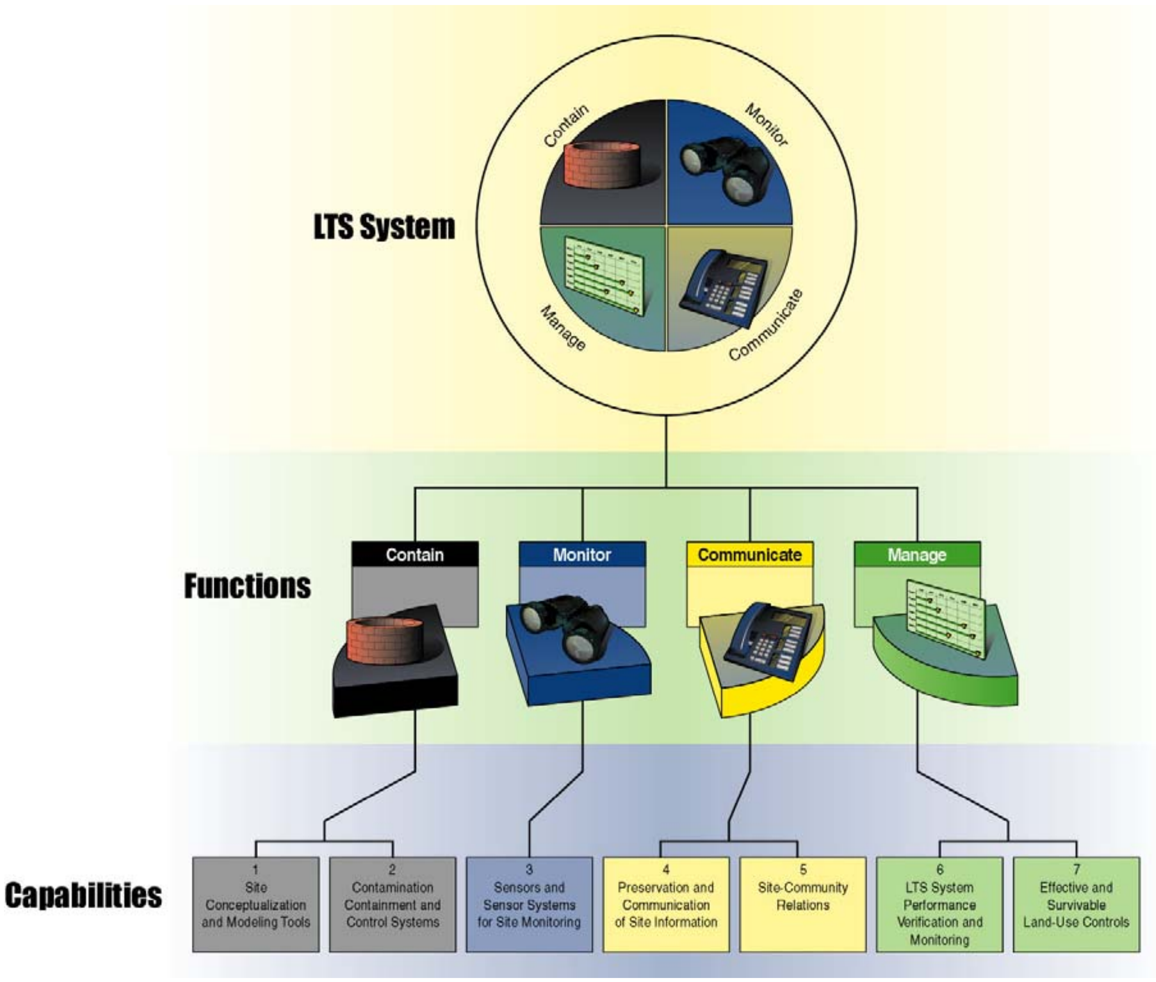


Figure 2-1. Flowdown of System Functions and Key Capabilities

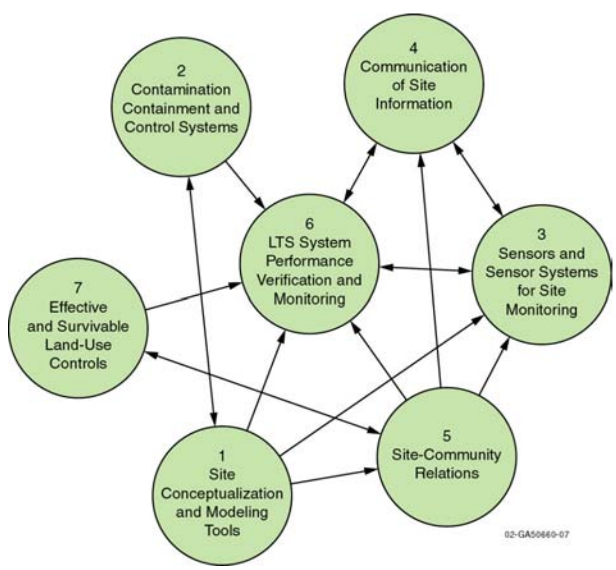


Figure 2-2. Influence Diagram for LTS Key Capabilities. Only the major lines of influence among key capabilities are shown.

Table 2-1. Capability Enhancements Necessary for a Long-Term Stewardship System

CONTAIN Residual Contaminants

Key Capability 1. Site Conceptualization and Modeling Tools

Enhancement 1.1	Improve geologic-hydrologic-biological-chemical-thermal conceptual modeling for long-term forecasting
Enhancement 1.2	Provide tools for long-term forecasting of environmental conditions relevant to predicted end states
Enhancement 1.3	Provide tools for modeling the community at risk
Enhancement 1.4	Conceptualize and predict containment/control system performance, including potential failure modes and levels of failure

Key Capability 2. Contamination Containment and Control Systems

Enhancement 2.1	Engineer the geologic-hydrologic-biological-chemical-thermal environment to limit contaminant toxicity and mobility
Enhancement 2.2	Design, build, and operate alternative (next-generation) containment and control systems

MONITOR the Site and the LTS System

Key Capability 3. Sensors and Sensor Systems for Site Monitoring

Enhancement 3.1	Identify contaminant monitoring needs for all media of potential transport or exposure and fill sensor technology gaps where monitoring solutions are needed
Enhancement 3.2	Establish site-specific parameters for environmental exposure routes and for both occupational (on-site) and non-occupational (community at risk) human routes of exposure
Enhancement 3.3	Improve sensors and sensor systems for monitoring active and passive safety systems

COMMUNICATE Within and Beyond the LTS System

Key Capability 4. Preservation and Communication of Site Information

Enhancement 4.1	Provide components for an integrated information visualization and display system
Enhancement 4.2	Provide an information system module for communicating system performance data
Enhancement 4.3	Provide options for intergenerational information archiving

Key Capability 5. Site–Community Relations

Enhancement 5.1	Improve understanding of what affects public trust and confidence
Enhancement 5.2	Involve the community in the conduct of site stewardship
Enhancement 5.3	Identify and solve problems that can undermine reliability and constancy in LTS institutions

MANAGE the LTS System

Key Capability 6. LTS System Performance Verification and Monitoring

Enhancement 6.1	Provide techniques and technologies to demonstrate, verify, and monitor long-term performance and management of contamination containment and control systems
Enhancement 6.2	Improve tools to verify performance of contamination containment and control and monitoring subsystems
Enhancement 6.3	Provide tools to verify and monitor the overall (technical and non-technical) performance of the LTS system
Enhancement 6.4	Integrate preventive maintenance requirements into site subsystems
Enhancement 6.5	Improve tools for collecting, analyzing, evaluating, and disseminating performance data
Enhancement 6.6	Develop science to ensure continuous improvement in stewardship implementation

Key Capability 7. Effective and Survivable Land-Use Controls

Enhancement 7.1	Develop legal pathway modules to help identify potential legal strategies, assess established agreements, and develop draft alternative legal instruments
Enhancement 7.2	Provide intergenerational archive options for maintaining land-use control information.

2.1.3 The LTS Technology Toolbox

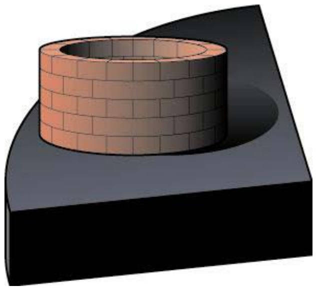
Every DOE closure site that is transferred into LTS because of residual contamination will require the four core functions of containing, monitoring, communicating, and managing. Yet each site has unique characteristics, and the stewardship system will have to be tailored to meet them. For this reason, many of the S&T-based capability enhancements in the Roadmap were formulated to provide a toolbox of technology options for stewardship planners and managers to design, install, maintain, and improve stewardship systems at individual sites.

The idea behind an LTS Technology Toolbox is that S&T does not dictate specific solutions for site stewardship. Nor is one technology the best choice, or even an appropriate choice, for every site. The products of the R&D pathways in this Roadmap will broaden and strengthen the choices available for efficient and effective stewardship, rather than forcing standardized, one-size-fits-all responses to complex conditions and issues.

The long-term vision for this technology toolbox is that a stewardship planner or manager would select and apply technology options through a sequence of steps. In addition to providing information about and access to "hardware" technologies, the toolbox would include aids for selecting and adapting these options for site-specific conditions and objectives (a methodology implemented in software.

For example, a planner or manager might begin with characterization data on the site's residual contamination and the site features that influence transport of contaminants by air, surface transport, or subsurface transport (tools to help with framing these data in site-specific models are described under Enhancements 1.1 and 1.2). A design aid provided in the technology toolbox would use this information to help the user determine appropriate target contaminants, surrogates, and performance indicators for monitoring subsystems (Enhancements 1.3, 1.4, and 3.2). Options for those monitoring systems (Enhancements 3.1 and 3.3) and for land-use controls and safety systems (Enhancements 3.3 and 7.1) would be readily accessible to the user, and the risk-reduction principle of providing defense-in-depth would be incorporated in these system design aids. If replacement or additional technologies for containment were needed (Enhancements 2.1 and 2.2), a design aid would guide the user in selecting among the options suitable for the specific circumstances. These design aids for selecting among monitoring, containment, and access control technology options would incorporate information on the site's community at risk (Enhancement 1.3) and site-specific exposure parameters for environmental risks and routes of potential human exposure (Enhancement 3.2).

The information on the monitoring, containment, and land-use control systems installed at the site will support the capability to verify and monitor site performance (Key Capability 6). Thus, this technology toolbox will provide LTS planners and managers with a set of generic, proven, risk-based, efficient components (the hardware) and a methodology (in decision aids) for selecting and tailoring them into the best systems for a particular site. The benefits will be measurable in increased cost effectiveness, lower maintenance costs, reduced occupational exposure, and increased safety and reliability for both the community and the LTS steward.



2.2 Contain Residual Contaminants

2.2.1 Key Capability 1 – Site Conceptualization and Modeling Tools

Understanding the interactions among site contaminants and the site-specific environment is essential to designing a stewardship system that will remain efficient and effective over time. Conceptual models are the basis for this understanding. Good conceptual models are essential for designing and implementing contamination containment and control (CC&C) systems, the systems for monitoring these CC&C systems, and the physical systems for site access control and access monitoring. All of these technology-based systems must be designed, implemented, and operated as subsystems of the total stewardship system. Adequate conceptual models for the site are the foundation for this integration.

The Roadmap team identified four aspects of Key Capability 1 in which substantial improvements can be made in the near term, resulting in products available to LTS planners and managers through the LTS Technology Toolbox.

1. Conceptual models that incorporate the best available scientific understanding of the site, including interactions between geologic-hydrologic-biologic-chemical-thermal (GHBCT) processes that control contaminant fate and transport.
2. Models that characterize site environmental conditions and predicted end states well enough to enable design and implementation of CC&C systems that can be effectively monitored and maintained to protect human health and the environment for the extended periods envisioned for LTS.
3. A tool for modeling the community at risk from residual contamination at the site. (The community at risk is the population that could credibly be exposed to residual contaminants.)
4. Improved capability to predict CC&C system performance, including potential failure modes and level of failure, in response to expected or potential environmental changes.

An R&D target was defined for each of these enhancements contributing to Key Capability 1. Each capability enhancement is described in more detail below, ending with its R&D target.

As noted in Chapter 1, the Roadmap team concentrated on S&T capabilities relevant to the near-term DOE closure sites. The Roadmap team assumed these sites will remove aboveground structures that are no longer being used or intended for ongoing future use. This Roadmap does not address aboveground, robust structures (reactor buildings, canyons, etc.), which will be decommissioned but may remain in place at some of the longer-term closure sites. Future phases of work on this Roadmap will need to consider enhancements and R&D targets specific to these structures.

Enhancement 1.1 Improve GHBCT conceptual modeling for long-term forecasting. The conceptual model for a site is an essential tool on which one can base the assessment of site health and environmental risks, the design of the site remediation and stewardship plans, as well as the design of the site monitoring system. The conceptual model also defines which contaminants and GHBCT parameters need to be modeled.

Site conceptual models for contaminant fate and transport are the basis for selecting the numerical models and analytic approaches used to design and predict performance of a remediation plan for the site. Output from the predictive numerical models, run with input data from the site monitoring system, is essential for updating the site performance assessment. The updated results from the performance assessment feed back into review and refinement of the data needed from the monitoring system. In turn, the conceptual models and this iterative predictive modeling define how the monitoring system will trigger contingency plans in the event of a contaminant release from containment.

The Roadmap team anticipates that improvements in GHBCT modeling will have a high impact on reducing technical uncertainty, since a better conceptual model provides better estimates of source terms, release rates, barrier failure mechanisms, and contaminant fate and transport. The impacts on reducing cost and reducing risks were estimated to be high because the conceptual model is fundamental to many other monitoring and CC&C techniques for reducing cost (see, for example, Key Capability 2).

Target 1.1: Sites have the capability to adapt the site monitoring system based on improvements to the GHBCT conceptual model for the site.

Enhancement 1.2. Provide tools for long-term forecasting of environmental conditions relevant to predicted end states. This enhancement will allow LTS planners and managers to characterize current environmental conditions and predicted end states well enough to design and implement CC&C systems that can be effectively and efficiently monitored and maintained over long periods. Essential to this characterization is an understanding of how site contaminants behave in these settings. An understanding of the current and projected environmental states at each stewardship site is needed to identify reasonable ranges for long-term changes that could lead to failure of CC&C systems over time. These conditions fall into five major categories: (1) climate change; (2) ecological succession; (3) pedogenesis (including soil structure and horizon development, bioturbation, desiccation, and freeze-thaw cracking); (4) landform processes (such as erosion networks resulting in topographic changes); and (5) land use, with primary emphasis on the next few generations.

Current performance assessment tools (short-term prototype tests, monitoring, and modeling) inadequately predict changes in the performance of CC&C systems in response to long-term environmental change. Reasonably well-developed methods from the natural sciences can be adapted for identifying and characterizing natural analogues for a range of system features (see Enhancement 2.2). Incorporation of location-appropriate analogues of natural processes into CC&C system design and performance evaluations could greatly strengthen system resilience to inevitable environmental changes. Not only will these alternative systems be much more effective; they will be much cheaper than current systems, which require extensive active management and maintenance to offset the impacts of natural processes. However, methods for integrating analogues with modeling and monitoring into evaluations of the long-term performance of CC&C systems are not yet well developed and are not yet widely deployed.

The modeling capability to be provided with this tool would support characterization of:

1. Transformation and attenuation processes (to more or less toxic forms, including radioactive decay, biodegradation, hydrolysis, and photolysis)
2. Mobility (including sorption, fixation, and complexation)
3. Bioavailability, also considering uptake, transfer, and other partitioning factors.

Target 1.2: Develop characterization technologies and analytical tools that enable long-term forecasting of system performance.

Enhancement 1.3. Provide tools for modeling the community at risk. Modeling tools are needed to enable planning and managing LTS with respect to the community at risk. Conceptually, the community at risk is defined as populations that live, recreate, or visit areas surrounding a site where contaminants are contained and access is controlled. Credible and defensible estimates of the size and distribution of the community at risk depend on estimates for four contributing factors:

1. The characterized source term of residual contaminants and the contaminant and surrogate species used as targets for monitoring
2. Reliability of detecting the monitoring targets
3. Meteorological and other physical conditions that affect transport and exposure
4. Social and demographic conditions, such as the types of use of adjacent areas and human behaviors.

The model will provide a defensible, credible technical framework for identifying the community at risk at any specified time during LTS based on input about nearby or resident human populations, visitors to the site or surrounding off-site areas, etc. The framework should be based on a peer-reviewed methodology analogous to that incorporated in federal regulations issued by the U.S. Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) for process safety at chemical plants that use large quantities of highly hazardous chemicals. These regulations require site-specific identification of source terms by quantity and characteristics, off-site hazards, and other factors. As a benchmark for the effort required to develop a legally defensible and socially credible framework, these EPA and OSHA safety regulations took years and hundreds of thousands of dollars to draft and finally promulgate as federal regulations.

Many large municipal governments already require a sampling strategy for the surrounding community from contractors that are remediating urban waste sites to "brownfield" status. The remediation contractor is required to determine the region of influence on the surrounding community, which is roughly equivalent to what is defined here as the "community at risk." Thus, there are practical precedents on which to build a modeling capability.

To be adequate for LTS, a model for the community at risk must diverge in an important way from many current modeling approaches. The LTS model must assume that the site boundaries will not remain static over time, given existing land-use controls, and that zoning ordinances may last only as long as the next change or two in county or municipal administrations. (Key Capability 7 addresses issues related to developing more effective, survivable land-use controls.)

Target 1.3: Develop modeling tools for estimating the community at risk for an LTS site.

Enhancement 1.4. Conceptualize and predict containment/control system performance, including potential failure modes and levels of failure. Most predictions of the long-term performance of CC&C systems could not benefit from actual performance data, given the very limited service lifetimes for existing systems. Designs using numerical models and short-term data often fail`` to incorporate events, such as erosion and biointrusion, that are being observed in some systems and could lead to failure, if unintended (Jones, et al). Without an improved capability to predict failure modes, severity of failures, and other aspects of CC&C system performance, DOE or other site stewards will be faced with aggressive and costly monitoring and replacement programs to ensure the continued effectiveness of CC&C installations.

There are experimental cover/cap systems that could be monitored and tested over the next five years and beyond to improve understanding (and thus prediction) of their responses to climatic cycling and biological processes. General knowledge of the natural processes that affect CC&C systems (including ecological succession, seismic effects on earth structures, erosion, pedogenesis, other natural processes) could be applied in predicting the long-term performance of these systems. The potential consequences of human activities must also be considered.

There are natural, historical, and archaeological analogues (such as Native American burial mounds and old concrete) for some cap/cover systems and engineered waste forms. These analogues can be studied to learn about the specific effects of less-frequent phenomena (such as earthquakes and other natural disasters) and longer time periods, as well as human disturbances. This work on effects of natural processes needs to be integrated with work on how human disturbances are likely to affect alternative CC&C systems (see Key Capabilities 5 and 7).

Improved capability to predict system responses to various expected or potential environmental and societal changes could reduce both costs and uncertainty of LTS for sites with engineered caps or covers. Routine inspection and monitoring could be safely reduced to focus on just the key target contaminants, surrogates, and locations. Repairs and replacement would be less frequent because prediction of time to failure would be more reliable and specific systems requiring repair could be identified more accurately. Cost savings will be greatest if the research and test results are available in time to influence final closure designs. For caps, covers, liners, and engineered waste forms, improved prediction of time to failure and knowledge of the characteristics of "failed" system could lead in the near term to a significant reduction in uncertainty—perhaps 50 percent—for predictions of long-term consequences at most DOE sites.

Target 1.4a: Provide performance data on experimental cover/cap systems and natural analogues, develop models for long-term natural processes that affect the performance of CC&C systems, and improve methodologies for prediction of failure modes and time to failure.

Target 1.4b: Provide a suite of techniques and technologies (e.g., models, natural analogues, guidance, performance indicators, and failure criteria) to improve planning, decision-making, design, monitoring, maintenance, and interpretation of monitoring data at and around CC&C systems.

The products of these two R&D targets assist enhancement of this capability, as well as Key Capability 6 (see Enhancement 6.1 [Section 2.5.1]).

2.2.2 Key Capability 2 – Contamination Containment and Control Systems

Virtually every DOE stewardship site will require long-term isolation of contaminants in vaults, disposal cells, waste tanks, or other units. To be successful, many of these CC&C systems may need to control contaminant migration for tens to thousands of years. During this extended control period, natural processes will tend to breach the containments and mobilize the contaminants. The engineering challenge posed by this need for effective long-term containment is unprecedented and daunting. Current design approaches typically fail to account for inevitable changes over the long term in the environmental setting of containment units.

Most DOE sites also have environmental contamination—in surface soils and sediment, in the vadose zone, or in groundwater—that will remain in place after the planned remediation programs conclude. For example, in 1997, the EPA estimated that 300 million cubic meters of groundwater under the Savannah River Site is contaminated. The Hanford Site and the Oak Ridge Reservation each had more than a million cubic meters of contaminated groundwater (NRC 1999, p. 24). At 21 selected DOE sites (including the above three), there are known plumes of contaminants in one or more of the following categories: radionuclides, non-radioactive metals and other inorganics, fuel hydrocarbons, high explosives, and organic compounds other than fuel hydrocarbons. At 15 of these sites, there are major plumes in two to five of the contaminant categories (DOE 2002a).

Long-term programs of pumping and treating groundwater, including extensive active interventions during an extended period of stewardship, continue to be the default controlling technology for most of these plumes. Also, the plan or expectation at several DOE sites is that runoff or subsurface water from contaminated locations (for example, sites of former French drains) will continue to be collected for ex situ treatment. These collection and treatment systems must operate effectively far into the future. Management of (potentially) contaminated water will be an enormous burden for site stewards unless alternative technologies are deployed to reduce the volumes of water requiring active management. Successful implementation of alternative technologies could yield huge savings, depending on the life cycle cost of the technology implemented. Just as important, alternatives that could contain and control the residual contamination by means other than collecting and treating water contaminated at low concentrations could reduce health and environmental risks, if they increase the long-term reliability of the system by reducing susceptibility to lapses in operation and maintenance (see Enhancement 6.4).

Most existing CC&C designs rely on conventional engineering methods that fail to incorporate key aspects of environmental change. Typical designs are collections of prescribed physical barriers to known or perceived release pathways (Rumer and Ryan 1995); rarely have they been evaluated as integrated systems. The limited field evaluations available to date show that many existing cover systems are already showing the effects of erosion and biointrusion (Jones et al.). Furthermore, other natural processes such as desiccation and frost penetration will affect the performance of compacted soil barriers (Smith, 1997). No known designs can withstand these natural forces for hundreds of years. Many systems currently deployed or being planned rely on continuous maintenance or other active interventions (such as water treatment). Other approaches require periodic replacement to continue functioning as intended.

Key Capability 2 will allow site stewards to deploy alternative CC&C systems that will function effectively over the long term with a significantly reduced degree of intervention (including maintenance, monitoring, and institutional control). To accommodate long-term environmental change, these alternatives would integrate and accommodate natural processes. Two general approaches offer significant promise for providing this capability. Each takes advantage of, or accommodates, natural processes. The first approach (Enhancement 2.1) is to engineer the thermo biogeochemical environment to limit the volume, toxicity, and/or mobility of contaminants. The second approach (Enhancement 2.2) uses barriers that continue to function over extended periods by mimicking natural processes and accommodating environmental change.

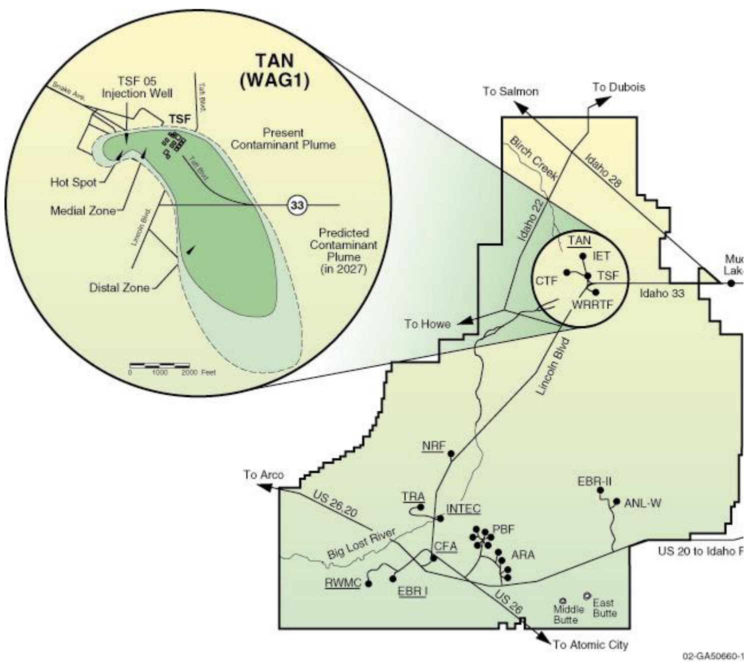
Enhancement 2.1 Engineer the GHBCT environment to limit contaminant toxicity and mobility. Contaminant toxicity and mobility are strongly influenced by the physical characteristics and chemistry of the contaminant and its surrounding environment. Techniques to control these attributes could target contaminants at the source (including, for example, landfills, disposal trenches, tanks, and contaminated soils at spill sites) or in the ambient environment (notably including groundwater plumes). The Roadmap team established one R&D target for control at the source and a complementary target for engineering the GBHCT characteristics of groundwater environments.

Target 2.1a: Deploy alternative technologies that detoxify or immobilize risk-driving contaminants at the source.

Target 2.1b: Deploy alternative technologies that reduce the volume of groundwater that would otherwise have been pumped and/or treated.

Bioremediation as an Alternative to Pump and Treat

At the Idaho National Engineering and Environmental Laboratory Test Area North, enhanced bioremediation and natural attenuation has augmented pump and treat technology. Laboratory and field treatability studies estimate a significant cost savings (20 percent) and schedule reduction (50 percent) compared with pump and treat only.



Achieving these targets will require developing and demonstrating a variety of physical, chemical, and biological manipulations that destroy some contaminants and control the toxicity and mobility of others in the diverse environments encountered in the DOE complex. No single technology or suite of technologies could provide the full range of capabilities required across the complex.

Some of these technologies could reduce stewardship requirements by allowing more aggressive remediation. For example, demonstrated technologies for destruction of organic contaminants in the environment could be applicable to some source zones and groundwater plumes in the DOE complex. However, additional development effort is needed to extend these technologies to the greater depths and complex geologic settings encountered at some DOE sites.

Biological techniques, including enhanced bioremediation, engineered wetlands, phytoremediation, and monitored natural attenuation, also have promise for reducing contaminant volumes and water treatment needs at locations contaminated with organic compounds or nutrient-rich explosive compounds (for example, energetics containing fixed nitrogen). For successful immobilization and detoxification of long-lived contaminants such as metals and most radionuclides, approaches that offer the greatest promise include those that emulate natural systems in which similar materials have remained stable over extensive periods. For example, in situ redox manipulation, bioremediation, and permeable-reactive-barrier systems all can stabilize contaminants by creating geochemical conditions that favor formation of stable compounds or by stimulating microbial communities to create such conditions. Thermal treatment techniques can reduce contaminant mobility by altering the physical setting, as in thermal desorption or vitrification, as well as by altering the rate of chemical changes.

Enhancement 2.2. Design, build, and operate alternative (next-generation) containment and control systems. Current designs for surface barriers (covers and caps) attempt to block contaminant release processes such as water flux, erosion, and biointrusion. These designs have failed in the short term because their barrier capability degrades with time. An alternative approach for designing, building, and operating sustainable covers mimics elements of natural landscapes that have already passed the test of enduring over time. This approach could substantially reduce system life cycle costs, which include costs for repair, replacement, and institutional control. Health risks to workers would be reduced by reducing active interventions for repair and replacement of deteriorating containment units. Long-term risks to the public would be reduced if the natural robustness of surface containment systems was improved (less risk to the public in the event that maintenance efforts lapse). Similar improvements could be achieved by applying these principles to design of subsurface containment barriers.

This enhancement is most likely to be effective when the CC&C system design integrates natural analogues into design, construction, modeling, and monitoring. Substantial progress has been made in developing alternative cover systems that mimic the geomorphology, soils, and ecology of natural settings that exhibit favorable attributes for long-term containment.

For example, evapotranspiration cover designs rely on a soil “sponge” layer to store precipitation. They use natural vegetation to return infiltrating precipitation to the atmosphere. Short-term studies, by Stoller at the INEEL (Anderson, 2002) and the Desert Research Institute at the Nevada Test Site and Sandia National Laboratory, show that evapotranspiration covers can be more effective than conventional designs in containing contaminants in sub-humid to arid climatic settings, while reducing maintenance intervention and land-use controls during LTS.

Broader application of this natural analogues approach will require additional work to verify performance, as well as site-specific studies to optimize the technology for new locations and to establish feasibility. Extending the approach to designs for humid-climate sites, such as Fernald, Oak Ridge, and Savannah River, will require further research, such as studies to identify humid-region vegetation succession patterns that are compatible with cap/cover survival and that require less maintenance than mowed grass.

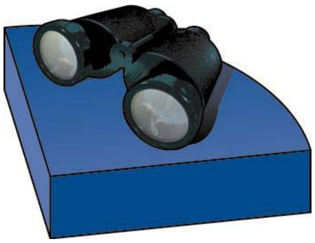
With respect to subsurface barriers, system life-cycle costs could be reduced by a variety of enhancements to existing technology. Examples of promising techniques include:

- Improved technologies for emplacement of slurry walls, grout curtains, and horizontal grout curtains
- Techniques to increase barrier life by stimulating “self healing”
- Identification and development of barrier materials that are chemically and physically compatible with site-specific contaminants and geologic settings.

As with Enhancement 2.1, the Roadmap team defined two R&D targets for this enhancement: one specifically for cover systems (surface barriers), the second for subsurface barriers.

Target 2.2a: Deploy cover systems that mimic natural processes and accommodate environmental change.

Target 2.2b: Deploy subsurface containment systems that mimic natural processes and accommodate environmental change.



2.3 Monitor the Site and the LTS System

For reliability and efficiency during the extended time frame of LTS, many existing monitoring systems will need to be improved or optimized. In some cases, changes will be necessary because monitoring decisions during the cleanup phase did not adequately consider long-term requirements or did not integrate monitoring needs into the CC&C system design. In other cases, site stewards will want to take advantage of step improvements in monitoring technologies.

Developing a framework for a site monitoring system permits the system to be optimized for that site. Consequently, risk reduction can be accelerated while cost decreases and efficiency of closure increases. State-of-the-art systems reduce cost and uncertainty, increase robustness and longevity, and decrease risk by allowing prompt implementation of contingency actions.

LTS planners and managers will need a methodology, incorporated in one or more user-oriented decision aids, to select components for contaminant-monitoring subsystems tailored for the conditions and objectives specific to a stewardship site. The methodology must take into account the multiple routes by which exposure may occur. It must also be compatible with the conceptual models developed under Key Capability 1, so that users have an integrated solution for planning an LTS system.

The capabilities covered as part of the Monitor function are (1) selecting sensor technologies and sensor systems and (2) identifying monitoring needs and filling sensor technology gaps. The S&T support for these capabilities will produce technology options for the LTS Technology Toolbox. Capabilities for verifying and maintaining operational monitoring systems are covered under Key Capability 6, LTS System Performance Verification and Monitoring.

1. *Contaminant Monitoring.* Contaminant monitoring systems for subsurface contaminants are typically designed using a "cookie cutter" approach—one size, shape, and set of monitoring components is assumed to work at all sites. The state-of-the-practice at DOE closure sites has recently been as much as 25 years behind the state-of-the-art in designing and implementing contaminant monitoring systems (Wilson et al. 1995; Scanlon et al. 1997). This approach leads to LTS monitoring systems whose life-cycle costs will grow, even over relatively short periods, to represent multiples of the site closure cost. For example, DOE has spent more than $300 million per year for site-wide water analyses across the DOE complex (Calef and Van Eeckhout 1992). The lack of a site-tailored, system-engineered monitoring plan may result in some combination of higher economic costs, increased risks to health and the environment, and greater technical uncertainty than the state-of-the-art in planning and system design could provide.
2. *Monitoring as Part of Site Safety Systems.* For the purposes of this report, a site safety system is a combination of technology (hardware and software), practices, and institutional controls used by a site to protect people from the hazards represented by residual contamination. Examples of safety system technology include fences, signs, and access-control gates; sensors for detecting airborne contamination or contamination carried by people or animals (e.g., radiation monitoring devices); and the communications technology (hardware and software) that connects sensors to recorders, warning devices, or data analysis and storage functions. Examples of practices are work rules, sampling routines, and procedures for responding to trigger events, such as detection of a contaminant or indicator at greater than a defined action level. Examples of institutional controls include legal or administrative mechanisms such as deed restrictions, easements, and land-use zoning ordinances. (See Section 2.5.2 for the EPA classification of institutional controls.)

Alternative Land Cover Research as a Stewardship Investment

Sandia National Laboratories tested the performance of six alternative approaches to an engineered landfill cover in an arid to semi-arid environment typical of the western U.S. The five-year project was funded by the DOE Subsurface Contaminants Focus Area and the Characterization, Monitoring, and Sensors Technology Crosscut Program. Two of the designs were those prescribed in Subtitle C of the *Resource Conservation and Recovery Act* (RCRA C cover) and RCRA Subtitle D (RCRA D cover). Of the four experimental designs tests, the anisotropic barrier cover and the evapotranspiration soil cover had flux rates and barrier efficiencies similar to that of the RCRA C cover. The anisotropic barrier incorporates soil layers that facilitate the lateral movement of water through drainage layers within the barrier. The evapotranspiration cover uses soil mixtures and compaction to hold moisture near the surface, where a mix of surface vegetation recycles nearly all of it to the atmosphere by evaporation and transpiration. Based on the results summarized below, the evapotranspiration design was selected for installation over a mixed waste landfill at Sandia National Laboratories.

	RCRA D	**RCRA C**	**Anisotropic**	**Evapotranspiration**
<u>Cover Design</u>				
Flux rate (mm/year)	4.82	0.13	0.16	0.19
Barrier efficiency	99.986%	99.999%	99.999%	99.999%
Construction cost ($/m^2)	$51.40	$157.54	$75.26	$73.89
<u>Landfill Application ($million)</u>				
Total capital cost	not reported	$3.55	not reported	1.76
Operation & maint., 30 yr.	not reported	$12.36	not reported	$2.07

Source: DOE 2000a

For this Roadmap, a ***passive safety system*** is one designed to perform its protective function without requiring intervention by a person. For example, passive safety systems, composed of hardware such as fences and physical barriers, signs, sensors, motion detectors, and alarms, are deployed around the areas of a site from which all unauthorized individuals are to be excluded to prevent exposure to residual contamination. Some individuals will be authorized to access the controlled area, and the measures for their protection will fall under the occupational safety and health standards imposed on the site steward. Thus, passive safety systems require sensors and monitoring capability to (1) ensure that the integrity of physical access controls has not been compromised, (2) detect individuals or animals that are approaching or have succeeded in breaching a physical access control, and (3) monitor the exposure of authorized individuals during their time in controlled areas. Depending on the way in which on-site contaminant monitoring and containment performance monitoring systems are integrated into the site-wide safety system for protecting human health and the environment, these systems may also be subsystems of a site's active safety system.

For this Roadmap, an ***active safety system*** is a system that requires a "human in the loop" (someone taking action) to protect persons in the event of an exposure incident. For example, active systems are placed in the areas around and outside the site to detect hazards and warn personnel to take some type of action. The action required may range from evacuation of certain parts of the area to remaining indoors for a period of time or even less severe precautionary actions. If a community monitoring system detects contaminants or indicators at a defined action level, then the site steward and local community officials must take action for the system to be effective in protecting the community. Thus, off-site sensors for contaminants and indicators are likely to be components of an active safety system.

2.3.1 Key Capability 3 – Sensors and Sensor Systems for Site Monitoring

Before a site is transferred from closure operations to stewardship, site monitoring systems must be deployed. Each monitoring system consists of an array of detectors (also called sensors or monitors) deployed in a tailored or graded approach to provide real-time detection and analysis of selected indicators. These indicators may be contaminants or contaminant surrogates, parameters relevant to performance of CC&C units, or signals indicating the status of physical access controls (e.g., human or animal penetration of a barrier and other barrier integrity indications). These detectors and the communications links from them should be selected to:

1. Reduce requirements for stationary laboratory sampling and analysis
2. Provide the levels of replication, detection, and precision needed to (a) comply with regulatory or locally based requirements for the site, (b) protect the community at risk and site access area, and (c) provide early indication of imminent or potential failure, or other need for corrective action, in some element of the overall LTS system.

Enhanced sensor system components and the design aids to select among them and tailor them to the site will be included in the LTS Technology Toolbox. The effort to provide these capability enhancements must begin now to substantially reduce the following negative consequences of current approaches:

- Costly last-minute work-arounds for unplanned needs
- Costly, labor-intensive efforts by the site steward to operate and maintain monitoring systems
- Costly single-point failures in monitoring systems
- Loss of capability to design for efficient, optimized maintenance.

Enhancement 3.1. Identify contaminant monitoring needs for all media of potential transport or exposure and fill sensor technology gaps where monitoring solutions are needed. Contaminant monitoring systems for LTS must be designed to cost-effectively collect data that ensure long-term protection of human health and the environment at sites with residual contamination and engineered CC&C systems. Current approaches to monitoring systems often focus on short-term monitoring plans, in which data are collected from numerous locations above-ground and at multiple depths below-ground. These data are usually collected quarterly and analyzed for an exhaustive list of constituents of concern. These comprehensive monitoring systems have not been optimized for long-term monitoring, where the goal should be to assess changes in site conditions as cost-effectively as possible. (Scarce resources are better spent on reducing risks, rather than accumulating excessive data that add little value to ongoing site performance assessment.) For the objectives of LTS, a site-specific monitoring system should be designed to reduce uncertainties and risks, while avoiding unnecessary costs. The ability to emplace these systems in the field cost-effectively needs further development.

Enhancement 3.1 assumes that enough data on the residual contaminants of concern (source terms) at sites entering LTS will be available to assemble a set number of sensors, hardware, and other components as technology options for site-specific selection and tailoring.

In addition to existing sensors and system components, LTS will require the development of multimedia (subsurface, surface, airborne, in-building) sensor technologies or techniques that either improve the capacity to monitor the presence and concentration of contaminants (or surrogates) or significantly decrease the cost of existing monitoring techniques. Previous and ongoing work on sensor development, which has been reviewed by others (e.g., Scanlon et al. 1997; Wilson 1982, 1983; Durant et al. 1993; EPA 1994a, 1994b) and will not be detailed here, can be used to establish a technical baseline for sensor development. New sensors and sensor-system technology are needed to measure GHBCT analytes and surrogates (see Enhancement 1.1), monitor remotely and wirelessly, miniaturize existing sensors, and increase reliability and calibration. The Roadmap team estimated that new sensors that reduce the need for invasive techniques would reduce costs for monitoring contaminants (or surrogates) and control/containment performance by 25 percent. Increasing the accuracy and reliability of sensors will reduce uncertainty and cost by a factor of two.

Techniques that allow for remote operations through telemetry or wireless technology are of interest, as are techniques, which in conjunction with modeling processes, allow for optimization of monitoring and/or CC&C systems. In situ techniques for developing GHBCT surrogate and analytes are needed that provide reliable data for the integrated LTS system performance monitoring capability (Enhancement 6.1). In addition, self-calibration of monitoring systems will improve the reliability of the monitoring data. Improving the robustness and reliability of the hardware components of the system will decrease the need for replacement and maintenance (Enhancement 6.4). Software development will provide a user-friendly interface to aid data integration and dissemination (Key Capability 4).

The R&D targets for this enhancement include development of one or more decision aids with the following capabilities:

- Identify the monitoring needed for different sites and transport media.
- Match the specific needs with existing and developing monitoring technologies.
- Identify technology gaps for which new technology is needed.

In addition, the R&D pathway includes the capability to initiate and complete the technology R&D to fill the identified gaps. Sensor technologies for multimedia environmental monitoring will be needed that incorporate new and innovative approaches to developing hardware, applications, and software. Hardware development may include new GHBCT methods, wireless miniaturization, remote interrogation, and non-invasive techniques. Applications and software will be developed to integrate point-volume sensing and to increase the reliability and calibration of sensors used in site monitoring systems. LTS sites will benefit particularly from remote, in situ, and continuous monitoring devices that yield real-time information or that can detect pollutants at very low concentrations.

Target 3.1a: Develop technology to fill 30 percent of identified gaps.

Target 3.1b: Ten percent of sensor arrays in field can deliver data wirelessly from subsurface.

Target 3.1c: Ensure that, 30 years out, 50 percent of sensors still meet their performance objectives.

Target 3.1d: Increase application of volume integrating methods, including non-invasive techniques, to 10 percent application in areas such as soil moisture and leak detection.

Enhancement 3.2. Establish site-specific parameters for environmental exposure routes and for both occupational (on-site) and non-occupational (community at risk) human routes of exposure. To provide proper protection of human health and the environment, scientifically defensible, site-specific criteria must be developed for setting the action levels and warning levels of target contaminants or surrogates being monitored on and off the site. For parameters related to protecting human health, at least two sets of criteria are needed to account for differences in cumulative dose, routes of exposure, protective systems, and risk acceptance by individuals who may be exposed. One set is needed for occupational routes of exposure, for authorized individuals who enter areas controlled by passive safety systems. A second set is needed for non-occupational routes—those faced by individuals in an identified community at risk. Environmental exposure parameters will depend on concentration limits set by environmental regulators.

Occupational routes of exposure apply to persons who are authorized to enter the site barriers for reasons of maintenance, inspection, cultural visitations, etc. This population at risk will be governed, monitored, and tracked for exposure based upon the regional, state, or other public entity that has jurisdiction. Exposure levels for chemical and radiological hazards are set by the various state jurisdictions, such as ecology or health departments. For chemical hazards with federally established regulatory exposure limits, identifying credible groups at risk is simplified. The applicable exposure standards are continually updated to reflect current epidemiological and toxicological information. There is therefore no need for an R&D target to augment, change, or add additional criteria for exposure to chemical, biological, or radiological materials for the occupationally exposed group. The current standards can be incorporated in the decision aids developed for selecting and tailoring the LTS monitoring systems.

As discussed above for Enhancement 1.3, the community at risk includes anyone who resides near or routinely visits an area adjacent to the site boundaries (which will change over time). The framework developed for identifying the community at risk (see Enhancement 1.3) must be compatible with whatever decision aids are developed to implement the methodology for establishing exposure parameters for this population. There are no regulations for 24-hour or domicile-based exposures to small quantities of chemical hazards over a prolonged period. However, monitoring targets (hazardous agents themselves or established surrogates) can be selected, based on the totality of potential contaminants of concern and the credible pathways by which they may be liberated from containment on the site and transported into the areas defining the community at risk. A defensible, credible methodology is needed, which could be used to establish non-occupational threshold limits.

> ***Target 3.2:*** Provide decision aids to help monitoring system planners and site stewards define monitoring system targets (hazards or surrogates), thresholds, and action limits by incorporating defensible, credible methodologies for establishing the site-specific parameters for environmental exposures and for occupational and non-occupational human exposures.

Enhancement 3.3. Improve sensors and sensor systems for monitoring active and passive safety systems. This enhancement is intended to provide an LTS steward with tools and options consistent with a generic set of safety system specifications. These specifications would reflect all of the sensor and monitoring requirements in both passive (on-site) and active (monitoring the community at risk) safety systems in the larger LTS stewardship system. The monitoring tools and options would include hardware, sensors, and monitors, as well as design aids for selecting and tailoring site-specific safety systems from these components.

The Roadmap team evaluated sensors for airborne contaminants and contaminated surfaces (including structural surfaces, materials, people, and animals) and determined that existing commercial technologies appear to be adequate to meet many (but not all) of the requirements for the active and passive safety systems needed by most DOE sites. (This does not apply to the state of subsurface contaminant monitoring discussed under Enhancement 3.1.) The S&T role for DOE will be to provide applications engineering in prescribing the specifications and the adaptation of systems that are already performing in the commercial sector and apply them to the environments and specific needs associated with a closure site. (Institutional controls, understood as non-physical land-use controls, present a different set of problems and are addressed by Key Capability 7, as discussed in Section 2.5.2.)

The monitoring data collected as part of passive safety systems can include signals for intrusion, erosion, topographical changes, and source term breaches. The monitoring systems to provide these signals should be able to discern incidental, chronic, or deliberate intrusions within controlled areas. The signal modes that would be integrated might range from satellite imagery to seismic pressure transducers with radio frequency output, to vapor and metal detectors operating on radio frequency.

Each monitoring subsystem of a passive or active safety system must be capable of connecting into a main risk-data integration system (the data integrator). The data integrator must be capable of (1) transmitting the various safety system signals arrayed for both passive and active protection, (2) providing real time indications (warnings and alarms), and (3) compiling data to assess trends over time. The data integrator must also respond to indicators of how well the various safety systems themselves are performing. For example, in sensors for an active safety system, the performance indicator could be as simple as an indicator light being on or off.

The risk-data integration system should itself be a component of the larger site information and performance monitoring system for archiving data, analyzing trends, providing warnings and alarms on defined tolerances, and activating additional systems (see Key Capabilities 4 and 6). It could be packaged in a standardized format to provide cost savings and increased reliability across the near-term closure sites (as well as for sites with longer closure schedules).

Automated monitoring subsystems for site safety systems, comprising arrays of embedded instruments, cannot entirely replace the need for manual collection and analysis of samples. However, a reasonable goal is to reduce the amount of stationary sampling by 40 percent from the level anticipated without automated monitoring, thereby reducing the associated labor costs by roughly 40 percent.

Target 3.3: Deploy a set of peer-reviewed safety system monitoring options and design aids for selecting and tailoring the monitoring subsystems for active and passive safety systems, to reduce capital and operations and maintenance costs by 40 percent during the first ten years of LTS, with anticipated increased savings during subsequent decades.

2.4 Communicate Within and Beyond the LTS System

All DOE sites need to provide information to the public, as well as to personnel working at or involved with the site, about site activities, environmental contaminants, associated hazards and risks, and the status of remedial actions to mitigate and monitor those risks. Local residents and community leaders have a direct interest in these site activities and need ready access to information about them. As discussed in Chapter 1, these information users must be viewed as included within the stewardship system as a whole. The historical examples of how land-use controls fail or endure over extended periods point to the importance of embedding those controls in more-general societal institutions, such as the informal but powerful social relationships expressed in concepts such as community and civil society.

In addition to the local communities that interact with the stewardship site directly and are clearly integral to a LTS system, other concerned parties exist, including regulators; members of Congress and their staffs; federal and state agencies; researchers; and entities in the for-profit business sector. Whether these parties are treated as within the stewardship system or external to it will depend on site-specific and time-dependent characteristics. However, they, too, will need information from the site's communications subsystems, and they may at times become sources of information for those subsystems. Without trying to be too precise about the exact boundaries of a site's LTS system, the system needs to be able to communicate both within itself and externally to a range of interacting parties.

2.4.1 Key Capability 4 – Preservation and Communication of Site Information

The Roadmap team identified specific technologies that need to be developed and or demonstrated to communicate information about the site, both within and beyond the stewardship system. Methods and tools are needed as part of the LTS Technology Toolbox to sustain knowledge about the integrated subsystems of the stewardship system. These subsystems typically combine natural, engineered, and human subsystems or components. Over time, subsystems and components will be upgraded and refined, and information on these changes also must be captured and maintained. Perhaps the biggest challenge is to ensure that the appropriate information can be retrieved when it is needed and in time to be useful.

More specifically, methods and tools are needed to:

- Obtain and transmit information about these subsystems and components (technology examples: on-site observations; remote, automated data collection; electronic, wireless, or optical transmission of collected data)
- Extract, integrate, and evaluate information (technology examples: mechanisms to evaluate statistical data-quality; artificial intelligence methods; mechanisms for integrating data functionally across platforms, formats, and forms; harmonizing taxonomies and network topologies)
- Interpret and display information according to the needs and requirements of diverse information users (technology examples: statistical and geographical/temporal trend analyses; visualization and decision-support mechanisms)
- Maintain, store, and archive information so as to preserve it and make it "impossible to miss" when needed (technology examples: compressed optical disk storage; warehousing; traceability; centralized and distributed architectures)

- Access and communicate stored/archived data and other information (technology examples: streamlined accessibility; tailored reporting; interactive communication)
- Identify predictors of future communication failures and develop mitigating approaches to reduce the frequency and severity of "failures to get the right information at the right time." (Technology examples: overt and unambiguous markers for future site and maintenance workers, methods of marking information about systems and components that have been altered or replaced).

The following benefits can be expected from achieving the R&D targets for Enhancements 4.1 through 4.3:

- Reduce labor-intensive activities, work-arounds, and the effects of human (and organizational) error
- Automate remote decision processes
- Plan better for technology migration and capitalize on commercial-sector successes
- Provide comprehensive profiles of site conditions (to support defense in depth)
- Reduce the system consequences of single-point failures
- Reduce unnecessary monitoring
- Improve the realism of estimated maintenance activities and costs.

Enhancement 4.1. Provide components for an integrated information visualization and display system. All sites across the DOE complex need to collect, analyze, and provide site-specific information on site environmental conditions, remedial actions, contaminant plumes, and monitoring programs to a variety of concerned or involved parties. These parties include site workers, program managers, regulators, and interested personnel at other DOE sites or at DOE headquarters. DOE sites are currently required to collect, evaluate, and communicate environmental data and interpretations to DOE management and to regulatory agencies on a periodic or as-needed basis. Means for presenting and disseminating this information to involved parties already exist, but they exist at different levels of development, complexity, and sophistication. They exist in a variety of presentation formats, and typically only provide information weeks, months, or longer after the original data were gathered. Further, this information may not be readily available to interested parties at other sites across the complex with similar interests or contaminant concerns.

An integrated, web-based, upgradeable, information visualization and display (IV&D) system, fully capable of presenting information ranging from raw data to graphic displays of data, on as near a real-time basis as state-of-the-art technology allows, would promote management coordination, efficiency, and decision making. If the same or compatible systems were used across the DOE complex, the LTS Program as a whole would benefit.

Current technology is a start, but it needs to be implemented to provide access across the Complex, as well as at an individual site. For instance, a shared information and knowledge base is needed. Commercial vendors have developed information systems with these capabilities for the oil industry, but some applications engineering is needed to adapt available approaches to DOE site activities. Beyond adapting existing capabilities, new technology or approaches are needed for analysis, data mining, and trend analysis of incoming data. New technology is needed for visualizing monitoring data in ways that different categories of users can understand and use. Technology must be developed or adapted for wireless or other networking of systems.

The development of an integrated public outreach program, for which the public access portion of the IV&D system would be the information technology foundation, would benefit DOE's interaction with the public by providing for information and feedback in both directions. Communicating with the public about ongoing remedial activities, proposed monitoring techniques, and technological advances would help to gain the public's confidence and foster support for the LTS Program. Educating the public with respect to known or potential hazards and corresponding risks will help mitigate the public's fear of those risks and facilitate acceptance of the LTS Program.

Finally, providing readily available means, through the IV&D public access interface, for stakeholders to respond with comment and information for site stewards is not just good public relations. It is fundamental and essential to continuation of stewardship activities over extended periods. Experience with other situations shows that those who live near a facility or site can be motivated, attentive monitors, at little or no direct cost to the facility. Involving the community can improve safety, as well as improving public acceptance of cleanup and stewardship activities, while reducing pressure for efforts that do little to reduce risks (NRC, 1993, 1996b, 2000; Chess et al. 1992; Clarke and Freudenburg 1993).

Target 4.1: Have in place at all DOE stewardship sites (and others working toward closure) a mature, functional, internet-based information management and communication system that is shared across the DOE complex. This system is to include two principal parts:

1. An internal communications system designed to accommodate data storage, data validation, user access, and information visualization and dissemination, to be used primarily by site personnel for their internal communications and to facilitate communication with DOE headquarters staff and regulators

2. An external communications system that has both a public Internet site and other means of access for the public, facilitates public outreach and education, and fosters feedback and response from the public to site stewards.

Enhancement 4.2. Provide an information system module for communicating system performance data. A component of Enhancement 6.5 (see Section 2.5.1) is the capability to communicate (disseminate) monitoring and evaluation information on LTS system performance. Thus, the IV&D system described above for Enhancement 4.1 should include modules for access, visualization, and display of information on performance of the site's CC&C, monitoring, and access control (passive safety) systems.

The Roadmap team did not define an R&D target specifically for this Enhancement. The R&D targets for Enhancement 4.1 and 6.5, if implemented as an integrated system, should suffice to provide this Enhancement.

Enhancement 4.3. Provide options for intergenerational information archiving. Optimal technical and administrative management of a LTS site requires planning for future failure or disruption. If a safety system or contaminant containment fails in the future, those responsible for responding must be able to obtain information to understand the risk and repair the failure. The information that must be preserved and communicated across generations includes information needed to protect people, secure a site when residual hazards are still present, and perform maintenance required by the technology or structures in use to contain and control residual hazards. A system is needed to preserve and hand down, across multiple generations, information that identifies site boundaries, defines the operation and maintenance of surveillance systems, keeps the community at risk aware with onsite markers, and communicates technical data (e.g., the contaminants of concern and the containment and monitoring designs for the site) with the reasons for archiving those data. The information a site will need to archive includes photographs, maps, relevant administrative reports, blueprints, specifications, and other means of conveying detailed information accurately.

A fundamental principle of information resource management is that retrieving all the needed information, and just the needed information, when it is needed is far more difficult than storing information. Another challenge is to preserve accessibility of the archived information, given the rapid evolution of modern electronic data storage technologies (old storage media and formats rapidly become obsolete and functionally inaccessible to users). Furthermore, the life-cycle cost of storing excessive amounts of unusable or virtually meaningless (to future users) data require careful selection and preparation of the data to be archived, to ensure that it continues to be informative to generations hence. Storing all the data generated from a site's operational, remediation, and stewardship activities is not the answer. Archival storage must be selective, planned, retrieval-oriented, cost-effective, and sustained.

Consequence of Failure to Preserve and Communicate Cleanup and Closure Information

Numerous anecdotal stories demonstrate the consequence of failing to communicate or preserve essential site cleanup and closure information.

- At one cleanup site, a landfill was capped. An operator was later asked to move a bulldozer to a nearby forest for clearing. Unaware of the capped landfill, the operator drove the bulldozer over the landfill, causing substantial damage to the cap.
- In numerous instances, state or local utility department crews open up underground utilities where hazardous materials have been buried, unexpectedly exposing themselves to the hazards. When the presence of the hazards is discovered after the exposures, there are decontamination and liability costs, as well as increased health risks.
- There are numerous accounts of sudden subsidence under the weight of a vehicle driven on old, unmarked burial grounds.
- For many facilities, particularly the older ones, drawings or other accurate engineering information are no longer available, or they prove to be inaccurate.

A system that implements the site's information archiving functions, called here an intergenerational archive, must meet these many requirements for responsible, responsive, and reliable storage and retrieval of intergenerational information. One goal is to maintain and update information over the long term, regardless of the medium used by new information technology. Equally important goals for an archive are to get the information to those who ought to care and provide them with the reasons why this information matters. Another important goal for an intergenerational archive is to support continuity in land-use controls. (See Enhancement 7.2 for further discussion of this aspect of the archive.) In addition, an intergenerational archive will instill confidence in the community at risk in the LTS system, as it will provide a record of site evaluations and actions taken in response to identified deficiencies.

Developing an intergenerational archive will reduce costs by eliminating the need to reproduce the S&T when repairs and improvements are made to LTS sites. It will decrease uncertainty and risk by providing reliable and accurate data about the site cleanup and closure, as well as technical information about containment and control of residual contamination and the monitoring systems for the site.

Target 4.3: Provide technology and information system options to enable stewardship sites to plan, implement, and maintain an efficient, optimized intergenerational archive. Include effective continuation of land-use controls among the objectives of these toolbox options.

2.4.2 Key Capability 5 – Site–Community Relations

Cleanup and LTS efforts at closure sites throughout the DOE complex are more likely to reduce environmental and health risks in both the near and long terms when the community at risk is involved. In contrast, a public that feels excluded from cleanup and LTS decision processes is more likely to become suspicious and openly hostile, as evidenced by the Federal Facilities Environmental Restoration Dialogue Committee advocacy of Site-Specific Advisory Boards in the face of funding shortfalls. Substantive community involvement in the design and conduct of LTS plans and activities will help to build the credibility of institutions responsible for LTS.

A 1996 report by an NRC committee, *Understanding Risk: Informing Decisions in a Democratic Society*, argues that better decisions are made—and controversies around risk decisions are better resolved—when all interested and affected parties are involved at the earliest possible point in both the characterization and analysis of risk. The report advocates an analytic-deliberative process, which entails a truly substantive public participation process involving the full range of interested and affected parties, decision makers, and technical specialists (NRC, 1996a). The analytic-deliberative process has been much discussed as a way of conducting risk-based evaluations in a participatory and productive way. Experience to date suggests that an analytic-deliberative approach will be no panacea for DOE sites (see Kinney and Leschine, 2002; see also Apostolakis and Pickett, 1998). Even so, an analytic-deliberative approach could prove valuable in reconsidering end states at DOE sites

Whether this approach or an alternative is adopted, the fundamental point is that the communities surrounding a stewardship site must be viewed as an integral part of the larger stewardship system for the site. If this component is not functioning effectively to support and sustain the containment, monitoring, access control, and communication objectives of the stewardship system, the system will fail long before the intended duration of site stewardship.

Enhancement 5.1. Improve understanding of what affects public trust and confidence. The development of viable LTS at a site will require that communities have a high degree of trust and confidence in those entities charged with designing and administering the LTS program. Either passive lack of public support or an adversarial relationship with the public could negatively impact the viability of LTS at a site. If public trust and confidence can be gained and maintained, the chance for success increases. Further, DOE will likely realize both short-term and near-term cost savings if it can build a cooperative relationship with the public affected by and interested in a stewardship site. In such a situation communities will be more likely to try innovative approaches to site cleanup, containment and control of residual contamination, and site monitoring.

At present, it would be unreasonable to claim that an improved understanding of factors affecting public trust and confidence will guarantee success. More research is needed to determine:

- What engenders public trust and confidence
- How the findings on effective trust-building efforts in other contexts might or might not be adaptable to DOE contexts and needs
- What effective public participation looks like, including further examination of the analytic-deliberative process
- How to measure effective public participation
- How to replicate successful public participation efforts.

The research to support this enhancement should include case studies of public participation efforts inside and outside DOE, pilot public participation efforts in LTS, and analysis and suggestions for replication of practices deemed successful.

Target 5.1: Finish case studies of agency actions that do or do not engender trust and confidence. Initiate full-scale field use of successful actions at selected sites.

Enhancement 5.2. Involve the community in the conduct of site stewardship. One finding from other contexts that appears highly relevant to DOE is the value of direct, two-way public participation with stewardship planners and site managers. A large body of literature exists on specific incidents in fostering (or obstructing) effective public participation in decision-making (see NRC 1996a and the References section therein, page 217). To date, however, objective measures are lacking for the effectiveness of the many suggested approaches to public participation. In a number of cases, relatively limited efforts at DOE sites to foster public participation have met with mixed results.

Substantive community involvement in the design and conduct of LTS may also result in significant cost savings. If LTS begins with agreement on future site uses, end states, and remedies, then the potential for near-term and long-term cost savings are great. Although public involvement provides no panacea, community involvement in cleanup decisions has already saved millions of dollars for DOE. At times local communities have identified and advocated these cost savings—for example at the Hanford and Rocky Flats sites. By contrast, in other instances short-term cost savings achieved by over-reliance on engineered or institutional controls appear likely to result in larger costs over time because of additional monitoring, maintenance, and rework to remedy failure.

Communities near closure sites are likely to be vigilant in assessing remedy selection decisions. An example is the virtual toolbox for identifying and organizing the long-term activities necessary for a site stewardship program, described in a report by the Rocky Flats Stewardship Working Group (RFSWG 2002). Other examples include sites already facing community intervention in DOE closure plans and schedules (Amchitka Island, AK; Weldon Springs, MO; and Mound, OH).

Target 5.2: Identify lessons learned about public involvement and use them to design and implement techniques that align DOE and community objectives for stewardship.

Enhancement 5.3. Identify and solve problems that can undermine reliability and constancy in LTS institutions. At the sites scheduled for early closure, such as Rocky Flats, DOE has consistently encountered extensive public skepticism toward assurances of continued vigilance in the future, whether by DOE or other federal stewards. Such skepticism is not without reason. Under the U.S. system of financing federal programs, grounded in the Constitution, not even formal congressional assurances of future funding are irrevocable guarantees. As pointed out by a study committee of the National Resource Council (NRC 2000), Congress not only makes the laws (passes legislation for the President's signature); it also "unmakes" them. Unless current funds are set aside through mechanisms such as a trust fund, only the members of Congress at some future date can guarantee funding for a program in the following fiscal year by passing an appropriation for it.

However, the same study committee pointed out that certain kinds of human institutions—such as libraries, archives, museums, and at least some National Parks—have in practice shown a reasonably impressive level of institutional constancy for periods of a century of more. A more systematic analysis is needed of this empirical record of constancy in some of our institutions:

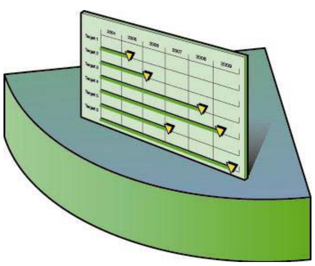
- To learn more about the factors most likely to improve confidence in the long-term performance of stewardship organizations

- To examine the possibilities for improved long-term performance that might be associated with alternative institutional arrangements
- To improve the likelihood that future stewardship organizations will be able to learn from failures, rather than denying their possibility, as well as learning from successes.

Although the challenges are significant, we clearly need to:

- Understand the nature and structure of organizations that are adaptable to new knowledge and new circumstances regarding risk, science, and concerns about legitimacy
- Develop and implement organizational arrangements that will channel information about their own failures, as well as those of other organizations, so that learning and adaptability are enhanced
- Identify the major forms of institutional failure and success and use this knowledge to improve LTS institutional reliability and performance.

Target 5.3: Design and implement institutional mechanisms that sustain and improve LTS.



2.5 Manage the LTS System

Technical management and administration of CC&C, monitoring, and communication systems implemented at a site will be required throughout the life cycle of an LTS site. Successful management of these subsystems within a total LTS system for a site means meeting multiple stewardship objectives. At the same time, cost efficiency in performing these essential activities is important. Optimization of the technical management and administrative activities aims at achieving all desired performance outcomes in the most cost-effective way—an optimal, total LTS system solution.

2.5.1 Key Capability 6 – LTS System Performance Verification and Monitoring

Optimal LTS system management requires reliable technologies (to be included as part of the LTS Technology Toolbox) to verify and monitor the performance of the various subsystems that contribute to the total system. These subsystems include the CC&C systems on the site, the human health and environmental safety systems both on and off the site, and the institutions with stewardship responsibilities.

The objective of subsystem verification and monitoring is to ensure that the planned performance levels of all the technical and non-technical subsystems are truly being met on a continuing basis. Open and well-documented verification procedures are necessary to assure the public and regulators that no incremental or additional risks to human health or the environment are occurring when these various systems are first installed and made operational. Thereafter, ongoing verification answers the question, “Is the total system still operating according to plan? ;” periodic re-evaluation addresses the broader question, “Is the plan truly effective for meeting all stewardship goals?”.

Both ongoing verification and periodic re-evaluation are essential to maintain effective stewardship over time, just as the initial verification is essential to ensure that new systems are operating as planned. For example, the software and hardware packages and subsystems that control and verify day-to-day safety system and access control operations must be re-evaluated at regular intervals for continued relevance to site objectives, advances in technology, and obsolescence. Non-technical subsystems (e.g., administrative procedures for land-use control and information management) also require reassessment at regular intervals to ensure they remain adequate, responsive to change, and cost-effective.

Enhancement 6.1. Provide techniques and technologies to demonstrate, verify, and monitor long-term performance and management of contamination containment and control systems. Management tools will be required to demonstrate that an initial CC&C system installation achieves its performance goals and to continue verifying and monitoring system performance over the long term. Long-term management should (1) continuously confirm that CC&C systems have not been breached and (2) provide early warnings of any needs for preventive actions. Long-term management of CC&C systems should also verify or refine projections of performance and risk reduction.

The Roadmap team identified six areas in which improvements are needed to meet the above requirements for verifying and monitoring CC&C systems:

1. Integrated Model of System Failure Modes, Release Processes, and Exposure Pathways. Basic methods for identifying generic failure modes and release processes are needed. So are general, idealized transport and fate models and a standard exposure assessment methodology. Existing methods and models have not been verified for site-specific conditions. Current models still represent fairly simple cases. They are not developed well enough yet to accurately represent real processes in heterogeneous environments, such as flow in fractured media, other preferential flows, site-specific attenuation characteristics, or susceptibility to and recovery from exposure effects. LTS planners and managers need improved models for guidance in deriving site-specific performance requirements. These requirements should be based on characterization of current and possible future environmental conditions, projections of contaminant release processes and pathways, and assessments of associated human health and ecological risks.

2. Selection of Monitoring Parameters and Criteria for Integration with CC&C Systems. Methods for choosing performance monitoring parameters and locations for basic CC&C systems are reasonably well developed, but they have not yet been tailored for, nor widely implemented in, complex systems designed for long-term protection. Similarly, methods for defining general criteria for these parameters are fairly well developed, but site-specific criteria using the Data Quality Objective (DQO) process defined by the EPA have not been effectively deployed for complex systems. Methods are needed for identifying, prioritizing, optimizing, and selecting risk-driving parameters and surrogates to be monitored, such as moisture flux from covers and outflow rate from reactive barriers.

3. Integration into CC&C Monitoring Systems of Leading Indicators for Containment Performance or Failure. Indicators are needed that ensure that individual components of CC&C systems, such as the barrier, collection, and treatment components, as well as whole systems, are operating within expected performance envelopes. Currently used indicators—for example, monitoring at the "point of compliance"—detect changes in performance "downstream" (down-gradient) of the CC&C system after a failure occurs. Early warnings—such as precursors of changes in system performance prior to containment failure—are needed so that effective action can be undertaken long before a failure occurs. To achieve effective, efficient CC&C for the long term, chemical, geophysical, and biological indicators that provide early warning must be identified and integrated into the performance monitoring plan during the design and construction phases of new systems or the maintenance and upgrade cycles of older systems.

4. Spatial and Temporal Optimization of Monitoring Networks. Uncertainties in conceptual models, key parameters controlling important fluxes, and forcing functions will require a statistically based monitoring network. The monitoring network will be characterized by (1) the zone of influence (support) of the sensors or sampling devices, (2) the spacing between sensors, and (3) the extent of the domain or site to be monitored. The monitoring networks to be optimized will generally include physical, chemical, and biological measurements in (or samples taken from) the subsurface, surface, and atmosphere. Initial applications will require separate optimization tools for each pathway because models and approaches that treat coupled systems realistically are currently limited. As research proceeds, a coordinated monitoring approach will become feasible and should be pursued.

   A capability for optimizing monitoring networks can be implemented as a set of tools, principally software tools, that will enable a site steward to decide where and how often measurements or samples should be taken and to determine whether (a) conditions have changed, (b) risks have increased, or (c) the remedial system is operating properly. The capability to reduce monitoring points and frequency while retaining the critical information needed for site performance assessment and monitoring of specific engineered CC&C elements will greatly reduce life-cycle costs. By optimizing the monitoring system, technical uncertainty can be reduced because the error bands on key performance outputs can be reduced by a factor of 2 to 5. Health and environmental risks will be reduced by a system optimized to provide the critical information needed for early warning of containment failure or contaminant movement.

5. Design and Emplacement of Monitoring Subsystems/Networks. This area covers the design and emplacement methodology associated with selection and tailoring of contaminant monitoring subsystems, including the selection of appropriate surrogates and indicators (see Enhancement 3.1 and Targets 3.1a through 3.1d). The design and emplacement techniques should build on the multimedia-monitoring framework for the site, through which sensor technology needs are identified. For the time periods required in LTS, emplacement methods such as highly controlled directional drilling or push technologies will be needed, to ensure that the monitoring systems can be repaired and upgraded. The network optimization tools described in the preceding paragraph would then be applied to design an optimized network.

6. Integration of Field Tests, Analogues, and Models in Performance Assessment and Feedback for Continuous System Improvement. The objective of CC&C systems at stewardship sites is to sustain protection over the long term. Thus, iterative performance assessments are needed to integrate ongoing field tests and analogues of system performance with predictive models. The process must also ensure that the resulting assessment information is fed back to the processes for reverification and re-evaluation, to guide appropriate modifications. Evaluation methods for field tests are well developed, as are general predictive models for performance assessment. However, observations of installed systems are not being widely recorded and shared in an organized, consistent manner. Natural analogues are not yet well represented in system performance assessments; methods for adaptive updating are not well developed; and results are not widely deployed for feedback to effective procedures to improve CC&C systems or monitoring systems.

S&T work for some of the six areas listed above is already covered in the targets for Key Capabilities 1, 2, and 3. Two additional R&D targets were added for Enhancement 6.1:

> ***Target 6.1a:*** Eighty percent of DOE sites going to closure and stewardship use a monitoring system optimization strategy.
>
> ***Target 6.1b:*** By 2008, half of DOE sites—and by 2010, all DOE sites—in stewardship or moving toward it plan to use contaminant surrogates and/or indicators in their LTS monitoring systems.

Enhancement 6.2. Improve tools to verify performance of CC&C and monitoring subsystems. This enhancement addresses the verification of monitoring and CC&C systems that function as subsystems of the larger LTS system for the site. Performance of each of these subsystems and their components according to design must be verified after installation (for example, no false positives or false negatives). Their continued performance "at or above design specifications" must be monitored throughout their operational life.

As noted in the introduction to Key Capability 6, an initial verification of the CC&C units and their associated monitoring networks is required after installation to ensure that all components are performing as designed. This initial verification should be open and well documented, including dissemination of results through the public access portion of the IV&D system (Key Capability 4), to assure the public and regulators that the systems are performing as promised. Performance of components and subsystems should be subsequently re-verified on a published schedule, again with the results available through the dissemination capability of the IV&D system. As noted in Section 2.4.1, the technical capability to verify component and subsystem performance can often be designed into the monitoring and data collection elements of the IV&D system.

> ***Target 6.2:*** Provide tools to verify CC&C system and contamination monitoring system performance.

Enhancement 6.3. Provide tools to verify and monitor the overall (technical and non-technical) performance of the LTS system. Enhancement 6.3 addresses the overall performance of the site-wide system for containing and monitoring residual contamination; controlling access to closed areas (land-use controls); and collecting, analyzing, and communicating information about these subsystems. Just as Enhancement 3.3 deals with providing LTS planners with a range of technology options (mostly commercially available) for designing active and passive safety systems tailored for a site, this enhancement deals with verifying performance of those systems after they are operational, and then continuing to monitor their performance on a regular basis.

Enhancement 6.3 also includes verifying and monitoring performance of:

- The data integrator system for the site (see Section 2.3.2)
- The information system that disseminates routine performance information, as well as alarms and warnings, to site personnel and to regulators and stakeholders (see Key Capability 4)
- The nonphysical aspects of land-use controls (see Key Capability 7).

System performance verification can be built into the software components of many site information subsystems (see Section 2.4.1, Key Capability 4). For example, from time to time, remote and wireless sensors must be manually challenged with a diffusion injection of known material concentrations to verify all of their design reliability requirements, such as repeatability, precision, accuracy, and sensitivity. These components and others in an integrated site-wide safety system will be driven by the data integrator subsystem. Functional requirements for these challenge tests and for other maintenance and repair schedules based on predictive fault methodologies (e.g., mean time to failure, control charting) can be incorporated into the data integrator.

This approach to verification will provide reasonable, cost effective schedules for manual checks or inspections of subsystems and components. The frequency and types of performance checks to be made can be tailored and built on incremental reliability analysis –all entered into the site's IV&D database (see Enhancement 4.1). Manual checks and tests will always be required, but they can be reduced considerably as reliability history builds. For example, the Fernald site is currently using a software package for predictive maintenance called TabWare, which thus far has proven adequate in optimizing maintenance surety with cost efficiency. Assessment tools to aid in periodic re-evaluations may include:

- A decision analysis module that integrates all site safety systems and components and recommends appropriate action or mitigation needed to ensure continued overall safety system performance.
- A knowledge management module that disseminates useful performance information (subsystem status, how well it is performing against plan, and flags for any issues that may need resolution) to stewards, regulators, and other stakeholders.

Target 6.3: Provide tools to aid site stewards in verifying, monitoring, and periodically re-evaluating the technical and non-technical aspects of site safety system effectiveness.

Enhancement 6.4. Integrate preventive maintenance requirements into site subsystems. Routine maintenance, including periodic inspection, mowing of vegetation, and replacement or repair of components, is a major cost component of LTS efforts planned for most DOE sites. CC&C measures at these sites include new waste-disposal cells, capped or entombed facilities and contamination zones, and containment of many groundwater plumes.

Methods for identifying preventive maintenance requirements are somewhat well developed; however, they have not yet been widely deployed to support efficient CC&C systems. Methods for diagnosis and for defining appropriate correction or repair measures are needed. Information on preventive maintenance requirements from existing operations and case histories should be compiled as a starting point. Some examples of available approaches that can be implemented more frequently and fully at DOE closure sites include enhanced emplacement approaches to repair and upgrade sensor systems and to repair CC&C systems.

The default technologies for most site closure plans depend on intensive maintenance for their effectiveness, such as frequent mowing and other measures to maintain artificial biological conditions on the site, continuous groundwater pumping and treatment, and frequent repairs to cracked or eroded barrier layers. Optimized protocols for maintenance of CC&C subsystems could reduce life-cycle maintenance costs significantly at most DOE sites. Improved understanding of maintenance needs for natural attenuation and reactive barriers could allow significant cost savings as well, on a life-cycle basis.

Target 6.4: Deploy technologies and protocols that significantly reduce the need for maintenance intervention of installed CC&C systems.

Enhancement 6.5. Improve tools for collecting, analyzing, evaluating, and disseminating performance data. Data on performance of the CC&C, monitoring, safety, and access control subsystems will need to be collected, analyzed, evaluated, and disseminated for purposes such as personnel safety, response actions required of site stewards, and system maintainability and continuous improvement. A risk-based approach should be applied to determining the amount, types, frequency and location of sampling or monitoring. The risk assessment required for this approach will be based on a comprehensive characterization of the residual contaminants at the site, the targets selected for monitoring, and the physical and demographic characteristics of each controlled-access area at end state for the site. Sampling and data collection can also be improved through the use of technologies such as in situ sample analysis and wireless data transmission. The Roadmap team estimated that 60 percent of the sampling can be performed remotely, with little or no labor required for routine sampling once the system is established. By combining risk-based approaches to identifying data requirements with improved sample and data collection technologies, the team estimated that overall cost savings could also be in the range of 60 percent.

Target 6.5: Issue action criteria for collecting, analyzing, and evaluating representative data on security and exposure systems, to reduce cost by 60 percent.

Enhancement 6.6. Develop science to ensure continuous improvement in stewardship implementation. Although the permissible land uses (and supporting end states) that will drive LTS requirements for an entire site will ultimately be defined at fairly large spatial scales, many end-state determinations are currently being made at the level of individual site sub-portions[3] or waste sites. At many sites (e.g., Savannah River Site), stewardship is being phased in as cleanup of individual site sub-portions is completed in serial fashion (DOE 2001). If risk-based corrective actions are implemented at individual site sub-portions without giving proper consideration to the effect of those actions on the site-wide LTS system, site-wide LTS requirements may become unclear or inconsistent**.**

Given this situation, as the details of site-wide LTS requirements develop, it may be necessary to reconsider the appropriateness of end-state determinations made on an interim basis (NRC, 2000). Further, technology advances may provide an opportunity to review end-state determinations for particular site sub-portions where a new approach, while consistent with the site-wide end state, could lower cost while providing equal or improved protection. For example, future technology could provide a method of neutralizing or destroying contaminants in a CC&C system at a cost that compares favorably with continuing containment, maintenance, and monitoring.

Reconsideration of end states in the context of the land-use aspirations of the communities surrounding DOE sites can result in situations where scientific and technical evaluations and information are seemingly set in opposition to community and other stakeholder values. Scientific tools are needed to ensure appropriate attention to the review of prior decisions, not only to meet community needs but also to ensure continuous improvement in the management of LTS, in terms of both cost-effectiveness and protection.

Target 6.6: Provide tools to ensure the continuous review and improvement of LTS and cleanup decisions.

2.5.2 Key Capability 7 – Effective and Survivable Land-Use Controls

As the term is generally understood in the federal government, land-use controls include physical, legal, or administrative mechanisms for limiting land or resource uses to minimize the potential for human exposure or to protect engineered remedies. The most frequently used physical controls are fences. The legal or administrative mechanisms are generally referred to as institutional controls. The EPA identifies four general categories of institutional controls (EPA 2000):

[3] Site portions are defined as "geographically contiguous and distinct areas for which cleanup, disposal, or stabilization has been completed or is expected to be completed … and where residual contamination remains" (DOE 2000b).

- Proprietary Controls can be imposed by current property owners on at least some subsequent owners, under states' real property laws. Examples are deed restrictions and easements.
- Government Controls are imposed by governmental entities irrespective of who owns the property. Examples include zoning laws, building codes, and drilling permit requirements.
- Enforcement and Permit Tools, under the EPA classification, are usually exercised by state or federal agencies through administrative orders or consent decrees. They require "performance of affirmative obligations," such as monitoring and reporting on the performance of institutional controls.
- Information Devices are additional measures to provide information, such as signs, state registries of contaminated sites, or the type of data IV&D system discussed in Section 2.4.1.

The EPA recommends that institutional controls be "layered" in ways that supplement and reinforce engineering remedies, although they are occasionally used as the sole remedies where active response measures are deemed to be impracticable under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). However, the literature on land-use controls includes many examples of the limitations of existing forms of control, how they can fail, and examples of how they have failed. In addition, a study committee of the NRC has expressed serious concern about the realism or prudence of relying on institutional controls and other land-use controls in the context of DOE sites (NRC 2000). The committee noted that many, if not most, of the existing control measures have shown a tendency to erode in effectiveness, often over relatively short periods of time. In this context, the following issues need to be addressed.

- Successes and Failures of Land-Use Controls. All sites with residual contamination are likely to rely on land-use controls to limit use or access for as long as the site contaminants pose a potential risk. Given the substantial risk that such controls will fail over time, an improved understanding is needed of: (1) conditions under which their successful operation is more or less likely, and (2) factors—such as human error, loss of interest, or the bureaucratic attenuation of information flows—that are most likely to influence success or failure. Studies of land-use control effectiveness and survival over time are also part of the effort needed to provide Enhancement 5.3 (see Section 2.4.2).

- Land-Use Controls and Containment Systems. Covers and subsurface barriers are unlikely to maintain themselves or provide comprehensive and effective control against outside intrusion in perpetuity. In addition, it is unclear at present how effectively physical barriers can be combined with legal restrictions or other land-use controls to enhance the protection afforded by these CC&C systems. More information is needed on the extent to which land-use controls can aid in maintaining the integrity of CC&C alternatives that use natural processes and natural analogues (see Enhancement 2.2). Features of these alternatives that appear "natural" to an uninformed intruder may fail to provide warning against activities that release contaminants.

- Land-Use Controls and Monitoring Systems. One of the R&D targets for Enhancement 3.1 (sensor technology to meet contaminant monitoring needs) is that, in 30 years, 50 percent of the sensors will still meet their performance standards. Enhancement 3.1 is also intended to reduce the need for invasive monitoring techniques. Survivable land-use controls are necessary to ensure that these monitoring technologies remain in place for the intended period of performance. Without effective, survivable land-use controls, the investment in remote sensor arrays and technologies may be at risk. Knowledge of the instrumentation, its location, the monitoring capabilities, and the data generated may be lost because of the inability to transfer that information to the current site steward, successor stewards, or governmental authorities. Land-use controls must also provide for appropriate access to repair, replace, add to, or remove sensors and other monitoring hardware at a stewardship site.

Enhancement 7.1. Develop legal pathway modules to help identify potential legal strategies, assess established agreements, and develop draft alternative legal instruments. Transferring cleanup sites to other parties as the long-term stewards is one of DOE's options. Yet, having another party accept even partial responsibility for managing a site with residual contamination remains a major stumbling block for the LTS Program. Major issues have included liability concerns, determination of end state, and cost. The cost issues concern provision for funding site operations and maintenance, contingencies (i.e., unexpected problems), data management, and other continuing costs of stewardship.

While the issues surrounding site transfer are complex and often have site-unique aspects, a reasonably small number of generic strategies for effecting transfer can be developed. Site managers could then adopt and adapt from "potential legal pathways" in the LTS Technology Toolbox (referred to here as "pathway modules") appropriate for their circumstances. Indeed, some standardization of approaches is necessary to avoid endless negotiation at each site with the potential steward(s) about the myriad possible options.

Strategies for ensuring long-term funding of LTS costs are critical to affecting the transfer of sites to non-DOE stewards. No organization will accept full liability or responsibility without some guarantee that funding will be available for operation and maintenance and for contingencies if an unexpected problem occurs (e.g., contaminants begin to migrate and threaten a community at risk).

The legal instruments effecting transfer of LTS sites out of DOE control are also important because they will limit the number and range of LTS activities at a site. For example, transfer agreements should:

- Implement safety system and institutional control technologies at LTS sites that are tightly focused and directed to be effective and efficient
- Identify final end-state land uses and corresponding legal instruments to implement only necessary and sufficient technologies
- Establish front-end legal requirements (current and future) to accompany the end state.

The benefits of developing a useful set of legal instruments, applicable across a range of actual site circumstances, include the following:

- DOE expenditures and closure costs will be significantly reduced if proven, generic approaches can be applied at multiple sites. The Roadmap team estimated cost savings of 50 percent or more on implemented LTS technologies expected by eliminating duplicative closure activities or closure activities that hinder LTS activities.
- Site closure plans will integrate the S&T options into LTS goals and requirements that can be easily transferred to the post-closure steward(s).
- Stakeholders will have an earlier opportunity to contribute to the decision-making process.
- Duplication of efforts between closure activities and LTS activities will be reduced.
- Dollars and technology development can be focused on agreed-upon LTS end-state needs for safety systems and institutional controls, as well as needs for containment or control of residual contamination and site-wide monitoring.

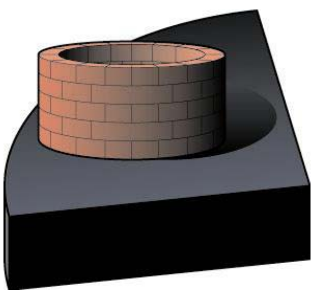
Target 7.1: Provide options for potential legal strategies and associated instruments to facilitate handoff of closed sites to final steward(s).

Enhancement 7.2. Provide intergenerational archive options for maintaining land-use control information. Land-use controls and survivability of data and information beyond the next few years are primary components to a successful site stewardship system. Inherent in the rapid advance of modern information technology is a high potential for obsolescence of the media on which site information is stored. The passage of time will also bring changes in stewardship responsibility, changes in property ownership on and near the site, changes in cultural norms in the surrounding community and the nation, changes in societal needs, and other changes. All of these changes will contribute to eventual loss of information and data. The degree and speed of that loss is not predictable, but it is inevitable. This inevitability drives the need to preserve essential site information as completely as possible, to ensure continued protection of human health and the environment. To succeed over the long term, the stewardship system must provide information continuity and access, not only for the next few years but also across multiple generations. For sites with residual wastes in containment, ensuring the preservation of data and information is more critical than it is for sites without wastes requiring containment or continued control. The R&D target for this enhancement is covered by the R&D target 6.3 for intergenerational archiving options.

3. BENEFIT, SCHEDULE, AND COST OF PURSUING CAPABILITY ENHANCEMENT TARGETS

The LTS system to be developed by implementation of this Roadmap will provide a strong foundation for continued improvement of our LTS capabilities. Chapter 2 described seven key capabilities to support the four LTS system functions (Contain, Monitor, Communicate, and Manage). In addition, Chapter 2 introduced 23 capability enhancements and 28 associated R&D targets to focus LTS S&T efforts and provide an LTS system that is resilient to human and natural forces, effective in protecting human and environmental health, and efficient in its use of national and local resources. This chapter (organized by system function) summarizes the projected benefits, schedules, and costs for attaining each target. A summary of the time-phased process by which those enhancements should be developed and implemented is also presented. Appendix C contains detailed pathways and task descriptions for each target.

The general technology areas addressed in Appendix C comprise numerous specific technologies that are in various stages of R&D (and in some cases limited deployment for remediation). Identification of the technology-specific R&D needs and pathway for each specific technology exceeds the scope of this effort and would duplicate effort that has already been done in support of remediation. Therefore, the R&D pathways and costs described therein are generic. Some steps and costs shown in the generic pathways can be avoided for technologies and applications that are currently under active development.



3.1 Contain Residual Contaminants

Development and application of improved CC&C capabilities can significantly reduce public health and environmental risk, program cost, and technical uncertainty. Subsequently, LTS site stewards will need to invest fewer resources in monitoring and maintaining a residual contamination site if there is a high degree of certainty that the CC&C structure(s) will continue to perform as designed, the structure is easily monitored, and the design life is of long duration. In addition, LTS site stewards will have a stronger technical basis for demonstrating to the surrounding community that DOE has appropriately closed the site and is endeavoring to ensure effective containment of residual hazards.

The benefits that can be derived from the development of new or enhanced CC&C capabilities suggested by the LTS S&T Roadmap include:

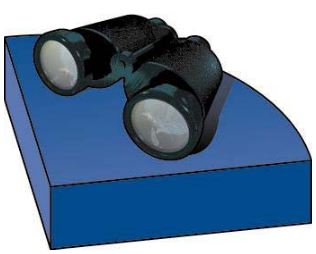
- Reduced and constrained uncertainty and risk through long-term forecasting with improved models.
- Better performance prediction through modeling of natural analogues.
- New technologies that reduce toxicity, mobility, and volume, thus less risk and cost.
- Improved CC&C system designs that mimic natural processes, resulting in less reduced and cost and better quantified and constrained uncertainty.

Table 3.1 presents the projected cost and schedule for each target at a summary level, additional details are presented in Appendix C.

Table 3-1. Projected Investment and Schedule to Achieve "Contain" Targets

Target		Projected Investment ($K)											Duration (months)
		FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	Total	
1.1	GHBCT Conceptual Model	200	400	300	300	300	400	100				2000	84
1.2	Forecast System Performance	x	x	x	x	x	x	x	x				
1.3	Modeling Community at Risk	300	300	300	100							1000	38
1.4a	Cover/Cap System Performance Evaluation	x	x	x	x	x	x	x	x				
1.4b	Improve Operation of Cover/Cap System	2,000	2,400	2,400	2,400	1,400	1,400	1,000	1,000			14,000	96
2.1a	Source Term Treatment	700	1,000	1,500	3,600	3,000	200					10,000	63
2.1b	Groundwater Treatment	700	1,000	1,500	3,600	3,000	200					10,000	63
2.2a	Natural Process Cover Systems	600	700	800	1000	1,200	800	700	600	400	200	7000	27
2.2b	Natural Process Subsurface Systems	600	700	800	1,000	1,000	800	700	600	400	200	7,000	114
Total Investment		5,100	6,500	7,600	12,000	10,100	3,800	2,500	2,200	800	400	51,000	

x – Scope, cost, and duration included in pathway for 1.4b



3.2 Monitor the Site and the LTS System

Current monitoring approaches often focus on short-term characterization, in which data are collected from numerous locations aboveground and at multiple depths belowground. These comprehensive monitoring systems have not been optimized for long-term monitoring nor have their hardware components been optimized for long-term reliable operation. Based upon fundamental differences at each of the DOE sites, specific monitoring programs need to be developed to bring state-of-the-art monitoring systems into the state-of-the-practice and to improve monitoring technologies so that they are designed for LTS as well as characterization. LTS site stewards will need to invest fewer resources in monitoring technology and maintenance if there is a high degree of certainty that monitoring systems will continue to perform as designed for a long duration. In addition, the LTS site steward will have a stronger technical basis for demonstrating to the surrounding community that DOE LTS sites are appropriately monitored to quickly identify LTS component failures and ensure the public is protected from residual contamination.

The benefits that can be derived from the development of new or enhanced monitoring capabilities suggested by the LTS S&T Roadmap include:

- Increased ability to detect and correct individual component failures (or pending failures) before they lead to system-wide problems

- Reduced life-cycle costs due to increased reliability and resilience of sensor hardware and data transmission systems

- Optimized data collection by enhancing the ability to collect the right data from the right place at the right time, and having it available near real-time.

Table 3-2 presents the projected cost and schedule for each target at a summary level, additional details are presented in Appendix C.

Table 3-2. Projected Investment and Schedule to Achieve "Monitor" Targets

Target		Projected Investment ($K)											Duration (months)
		FY03	FY04	FY05	FY06	FY07	FY08	FY9	FY10	FY11	FY12	Total	
3.1a	Monitoring Technology Gaps		2000	800	800	800	800	800				4,200	72
3.1b	Wireless Subsurface Sensors	100	1,700	1,700	1,700	900	200	100				6,400	78
3.1c	30 Year Sensor Life	100	300	400	400	300	600	500	100			2,700	90
3.1d	Volume Integrating Methods			100	2,000	2,000	2,000	2,000	200			8,300	72
3.2	Define Monitoring System Targets		500	500	500	500						2,000	48
3.3	Safety System Monitoring				900	500						1,400	19
Total Investment		200	2,700	3,500	6,300	5,000	3,600	3,400	300	0	0	25,000	

3.3 Communicate Within and Beyond the LTS System

Improved internal communication systems are needed to help site stewards preserve, evaluate, and share data across LTS sub-systems so that system functionality and performance is clearly understood. Understanding and communicating the relationship and interaction of system components and the trending of their performance is central to maintaining an optimized system. Community members, regulators, site stewards, and other local stakeholders also need confidence that they and their successors can easily access all necessary information to assure they are safe from residual contamination. The development of an integrated communication capability would benefit DOE's interaction with site managers and stakeholders by enabling a two-way exchange of information to ensure the LTS system is performing as designed. Educating the public with respect to ongoing remedial activities, proposed monitoring techniques, and technological advances would help gain the public's confidence and foster acceptance of the closure activities and the corresponding LTS program. A concerted effort to optimize stakeholder relationships would also generate a higher degree of trust in site information and enable LTS site stewards to invest fewer resources in reporting to stakeholders, regulators, and management.

The benefits that can be derived from the development of new or enhanced communication capabilities suggested by the LTS S&T Roadmap include:

- Preservation of site information (e.g., historical, source term, characterization, remediation, and monitoring) through an intergenerational archive that supports ongoing analysis, trending, and decision making

- Availability and use of data analysis and visualization tools to facilitate access and understanding of archived data

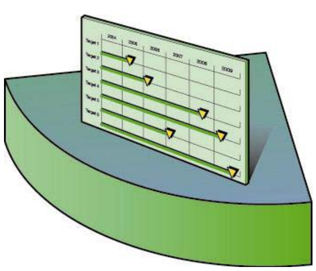
- Increased understanding and application of factors that increase public trust and confidence

- Improved mechanisms to ensure LTS institutional longevity.

Table 3-3 presents the projected cost and schedule for each target at a summary level, additional details are presented in Appendix C.

Table 3-3. Projected Investment and Schedule to Achieve "Communicate" Targets

Target		Projected Investment ($K)											Duration (months)
		FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	Total	
4.1	Internet Based Information and Communication System		500	400	400	200						1,500	48
4.3	Intergenerational Archive		100	100	200	100						500	42
5.1	Case Studies on Trust and Confidence	300	400	300	100	100	100					1,300	72
5.2	Align DOE and Community Objectives		500	300	300	300						1,400	48
5.3	Institutional Mechanisms for LTS		300	500	400	100						1,300	42
Total Investment		300	1,800	1,600	1,400	800	100					6,000	



3.4 Manage the LTS System

Administrative and technical management capabilities establish mechanisms by which containment, monitoring, and communication enhancements are deployed and implemented. Many of the currently deployed and planned LTS systems are unproven over the long term and are specific to individual sites. Additionally, site-specific performance requirements are not fully integrated into a systemic approach. LTS costs, risk, and uncertainty will be significantly reduced if proven, generic approaches can be deployed and applied at multiple sites. Enhanced management capabilities will allow LTS site stewards to effectively optimize LTS systems and ensure that reductions in program cost, health and environmental risk, and technical uncertainty are realized.

Benefits to be derived from the development of new or enhanced management capabilities suggested by the LTS S&T Roadmap include:

- Implementation of optimized monitoring and containment strategies

- Improved ability to verify and periodically re-evaluate the performance of containment, monitoring, information, and site safety systems
- Reduced need for maintenance intervention through integration of preventative maintenance requirements into site sub-systems
- Continuous improvement of stewardship implementation
- Facilitated handoff of closed sites to long-term stewards through generic legal strategies and associated instruments.

Table 3-4 presents the projected cost and schedule for each target at a summary level, additional details are presented in Appendix C.

Table 3-4. Projected Investment and Schedule to Achieve "Manager" Targets

Target		Projected Investment ($K)											Duration (months)
		FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	Total	
6.1a	Monitoring Optimization Strategy	900	1,700	1,600	2,100	1,400	1,800	1,500	1,300	2,100	1,600	16,000	117
6.1b	Contaminant Surrogates and Indicators		200	800	800	800	800	800				4,200	72
6.2	Verify Containment System Performance			300	200	200	400	200	200	200		1,600	84
6.3	Safety System Effectiveness			100	200	100	100	200				700	54
6.4	Reduce Maintenance	500	500	600	100	100						1,800	57
6.5	Issue Action Criteria for Data			150	150							300	23
6.6	Decision Review and Improvement			500	500	400	400	400				2,200	60
7.1	Legal Strategies for Site Transfer		600	250	250	100						1,200	42
Total Investment		1,400	3,000	4,300	4,300	3,100	3,500	3,100	1,500	2,200	1,600	28,000	

3.5 Summary Schedule

Figure 3-1 shows the interdependency of the R&D targets during their development. While work on all of the targets could be commenced immediately, it is recognized that resource constraints are likely to preclude this approach. Figure 3-2 provides a summary level schedule and projected investments for development of the targets that allows early implementation of portions of the enhanced $S = (MC)^2$ system while other portions are still under development. It should also be recognized that for many of the targets, significant practical value will be obtained prior to completion of the target. Figure 3-3 presents the cumulative number of R&D targets completed for each fiscal year, assuming work commences in FY03. Half of the targets will be fully attained by 2008; the remaining targets will be attained by 2012 in time to support the substantial LTS responsibilities DOE will have at that time. Figure 3-4 shows the timing of attaining R&D targets (and, thereby, an enhanced $S = (MC)^2$ system) in the context of DOE's LTS responsibility over the next 100 years. Appendix C provides additional detail on intermediate products and deliverables for each target.

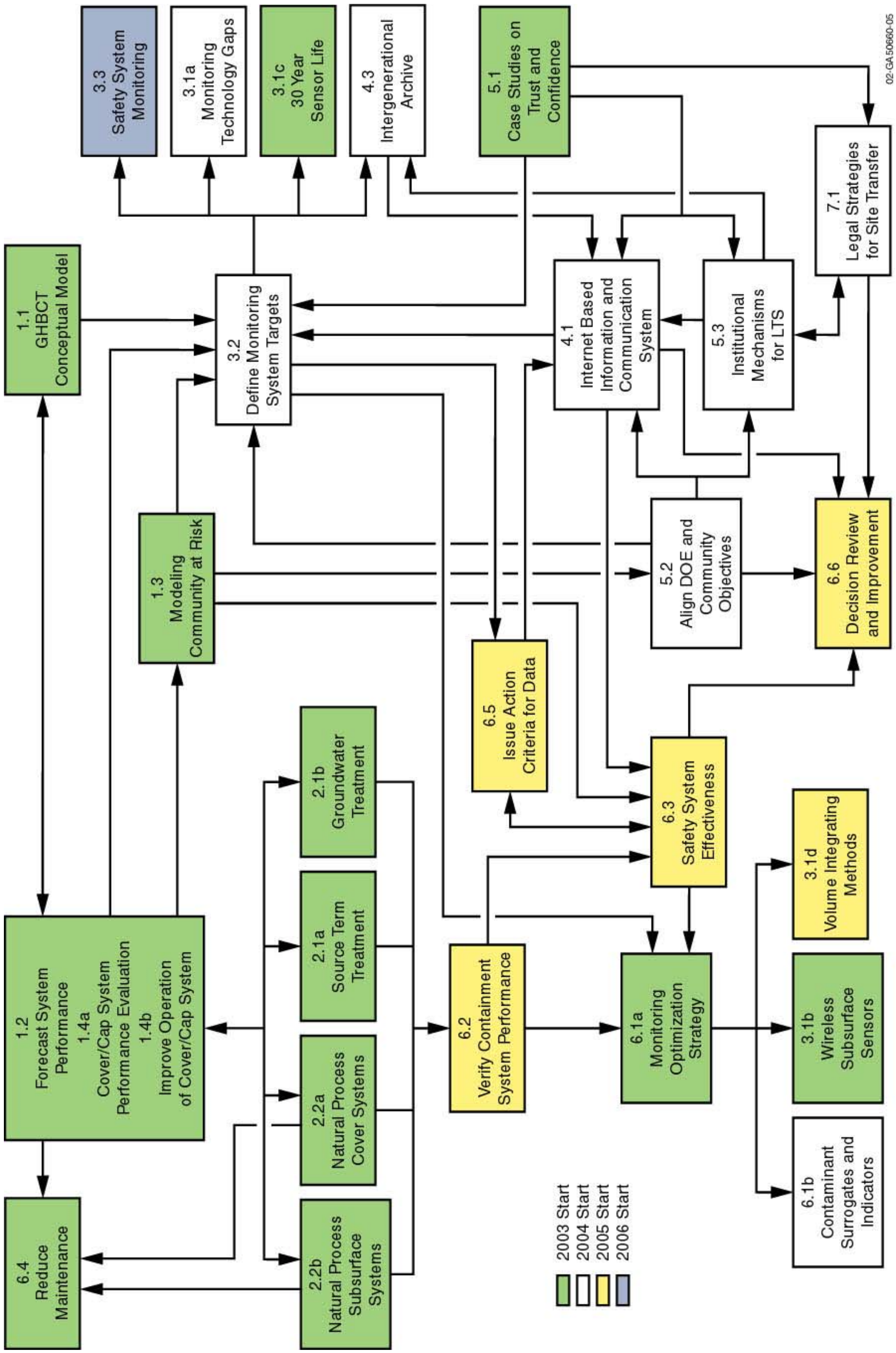


Figure 3-1. Interdependency of Near-term R&D Targets.

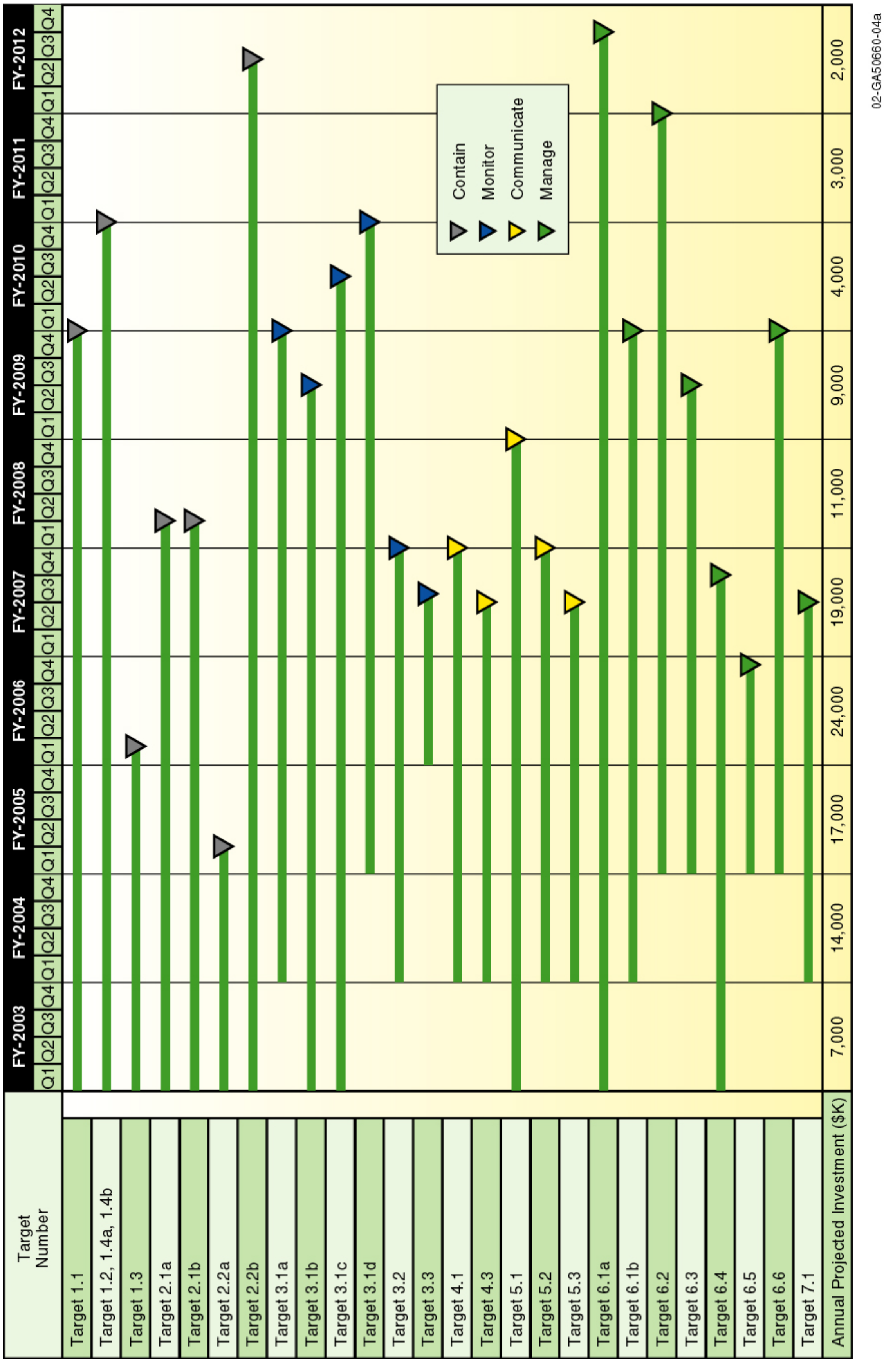


Figure 3-2. Summary Schedule and Annual Investments for Developing Near-term R&D Targets.

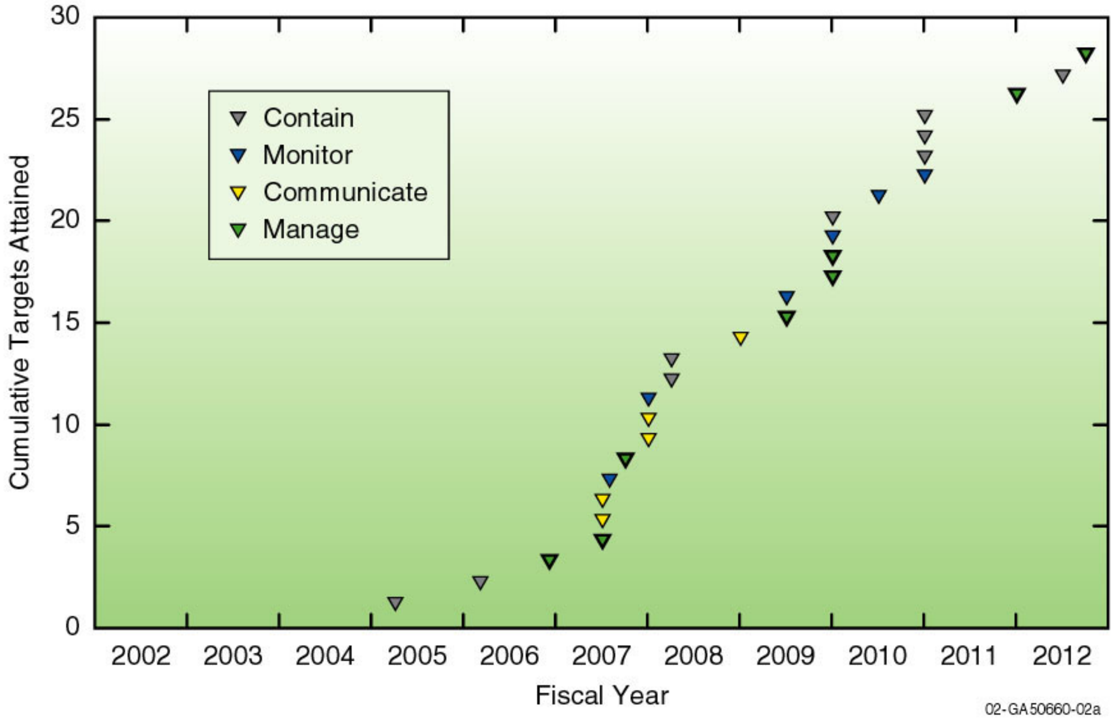


Figure 3-3. Cumulative Targets Attained Per Fiscal Year

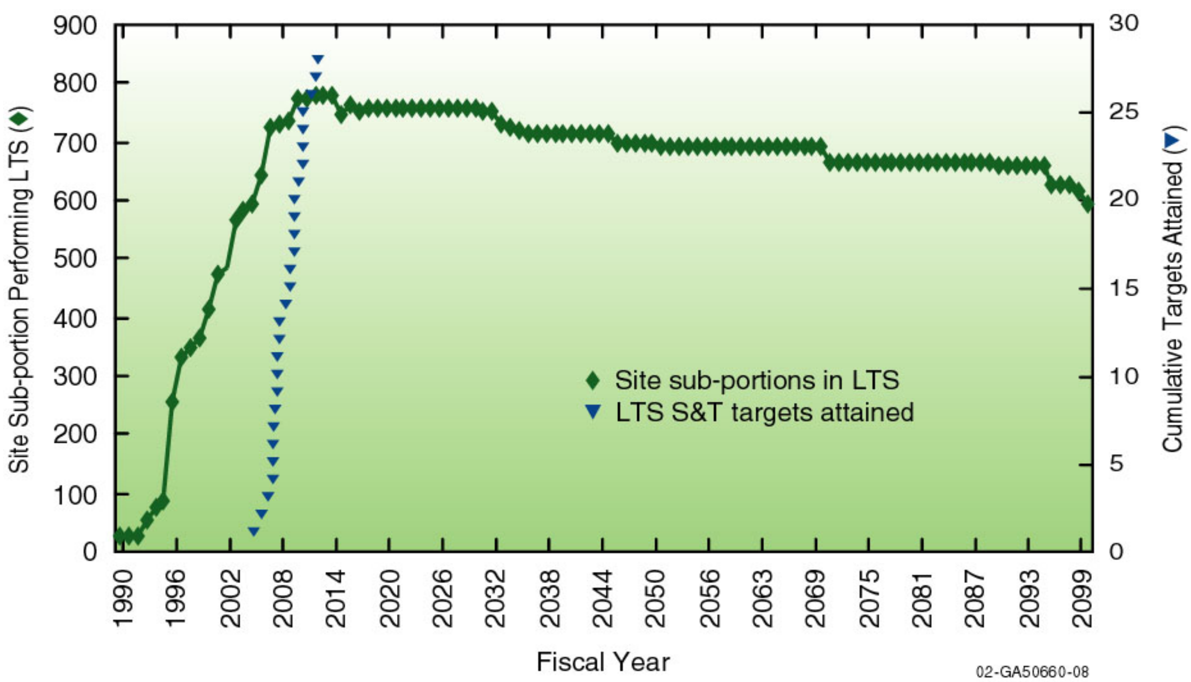


Figure 3-4. Timing of Attaining R&D Targets in context of DOE's LTS Responsibility

4. CONCLUSIONS AND PATH FORWARD

4.1 Concluding Messages

The LTS S&T Roadmap team learned a great deal from the roadmapping effort. Two specific messages need to be stated explicitly.

Message 1: A Strategic Plan for LTS Science and Technology Will Help DOE with Site Closure Decisions.

The final, critical step to remediation and closure of almost all of DOE's sites is acceptance of the site into stewardship. DOE has determined that 129 of the sites for which it has environmental management responsibility will require stewardship following completion of site operations, due to residual contamination at the site. This requirement for LTS exists because either the technology does not exist to remediate the site for unrestricted use or the effort would be prohibitively expensive with existing technology. DOE has invested a good deal in S&T to address technical issues raised in the course of environmental management of its sites. However, DOE has not yet developed a strategic vision and plan encompassing all of the S&T required to assure regulators, stakeholders, and potential stewards that LTS will be effective for the considerable periods of time during which residual contamination will present risks. DOE will use this Roadmap to establish the strategic vision for LTS S&T and develop an LTS S&T Strategic Plan.

Message 2: To Be Effective in the Long Term, Stewardship Must Be Approached as a System.

Each capability within the LTS system adds intrinsic value toward meeting LTS objectives, but the greatest benefit will be realized only when those capabilities and associated tools are employed as an integrated system. While efforts to achieve identified capability enhancements could commence immediately, it is recognized that resource constraints are likely to preclude this approach. The integrated schedule presented in Chapter 3 provides a pathway to develop the components of the overall system in a manner that allows early implementation of portions of the system while other portions are still under development. As such, capability enhancements can, and should, be implemented as sites gain experience with their particular stewardship requirements.

The LTS S&T Roadmap team believes that site stewardship can only remain effective over the long term if it is approached as a system of integrated functions, capabilities, tools, and techniques. Accepting this systems view of LTS has consequences requiring substantial effort on the part of DOE:

1. Adopting a systems view requires a paradigm shift within DOE organizations that have LTS responsibilities. The capabilities defined in Chapter 2 are, for the most part, categories rather than single, fixed solutions. The S&T products from most of the pathways will provide options and generic technologies requiring tailoring to the needs of individual sites. A good systems solution for one site may not be a good solution for another, and every site should aim at its own optimal solution.

2. Stakeholders are an essential part of the LTS system for each site, not external to it. The social science research on the many failures and exceptional successes in maintaining a social-administrative process, like LTS, shows that the involvement of the surrounding community is essential for such activities to survive from one generation to the next. This LTS S&T Roadmap provides a basis for building the participation of stakeholders in making credible, defensible LTS decisions that have community commitment to sustain them.

4.2 Benefits of Roadmap Implementation

This Roadmap recommends R&D pathways to provide a system of integrated capabilities needed for DOE to influence LTS policy and best manage investments to implement an effective LTS program. Implementing this LTS S&T Roadmap will provide several near-term programmatic benefits for DOE:

1. The Roadmap presents a vision for a full suite of LTS capabilities and identifies near-term enhancement opportunities that provide for step-change improvements in risk reduction, cost reduction, and assuring timely schedule completion.

2. The Roadmap identifies a broad spectrum of tools needed to fill an LTS Technology Toolbox that will link state-of-the-art technologies with the state-of-the-practice for LTS planning and operations to enhance DOE's ability to cost effectively meet closure schedules and keep LTS commitments to local communities and other stakeholders.

3. The Roadmap is a catalyst for coordinating and integrating dispersed efforts within DOE and with other federal agencies in developing technology to improve cleanup and stewardship.

4.3 Recommended Path Forward

The benefits provided by this LTS S&T Roadmap can be expanded and improved with the participation of other state and federal agencies and non-governmental organizations with recognized expertise and the willingness to participate. A cooperative and coordinated effort between DOE and other agencies is needed, and this Roadmap can play an important role in that effort. DOE can learn from others, just as others can benefit from DOE efforts and lessons learned. Additionally, because the time frame of the Roadmap was restricted to the near term, some important capability enhancements were not identified nor were related enhancement pathways developed. To provide a more comprehensive, long-term view, the Roadmap should be expanded to provide needed longer-term benefits. The result of these broader efforts would be a follow-on S&T Roadmap providing for LTS capabilities and technologies applicable to a wider range of sites and situations than those covered herein.

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